THE MINING ASSOCIATION OF GREAT BRITAIN.

# RECORD

OF

# FIRST SERIES

(1908-09)

OF THE

# BRITISH COAL DUST EXPERIMENTS.

1910.

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# RECORD

## OF THE FIRST SERIES

OF THE

# BRITISH COAL DUST EXPERIMENTS

Conducted by the Committee Appointed by
The Mining Association of Great Britain.

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A RECORD OF THE EXPERIMENTS CARRIED OUT DURING
1908 AND 1909 AT THE
ALTOFTS EXPERIMENTS STATION.

Printed and Published by
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# PREFACE.

THE following Record gives an account of the first series of Experiments carried out by the Committee appointed by the Mining Association of Great Britain to thoroughly investigate the phenomena of coal dust explosions. The explosive nature of a mixture of coal dust and air in the absence of inflammable gas has been conclusively proved. These Experiments have been conducted solely in the absence of inflammable gas, and no Permitted explosives have been employed. They have been directed towards studying the effect of dustless and stone dust zones upon explosions of a mixture of coal dust and air. The investigations dealing with watered-zones and other means of preventing or mitigating an explosion are in a preliminary stage only. Future experiments will include the use of Permitted explosives and a study of the influence of coal gas as a factor in the phenomena.

(Signed) LINDSAY WOOD,
W. E. GARFORTH,
C. PILKINGTON,
J. T. FORGIE.
W. W. HOOD,

LONDON,
*8th November*, 1910.

Mining Engineering 1911 v.1 Bodleian 540 d 2 Jeff

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# REPORT OF COMMITTEE ON BRITISH COAL DUST EXPERIMENTS.

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To the Members of the Mining Association of Great Britain.

Gentlemen :—

Your Committee beg to submit a Report on the British Coal Dust Experiments, carried out at Altofts since May 1908.

Having regard to the fact that attention was drawn more than a century ago to the part played by coal dust in colliery explosions ; that a controversy respecting its inflammability and power of propagating an explosion has existed for over thirty years ; that many colliery explosions, attended by great loss of life, have occurred during that period ; that scientific men in this and other countries have repeatedly pointed out the danger of coal dust ; the Committee think that, before referring to the details of their experiments, it would be of interest to give a brief history of the chief events which led to the present investigation, and to the establishment of an Experimental Station.

The recognition of the danger of coal dust in underground workings may be said to date from the time of John Buddle, the eminent North of England colliery viewer, or mining engineer, who, after the Wallsend Colliery Explosion on September 3rd, 1803, stated that "the workings were very dry and dusty, and the "survivors, who were the most distant from the point of explosion, were burnt by "the shower of red hot sparks of the ignited dust which were driven along by the "force of the explosion."

The danger was again referred to by Messrs. Faraday and Lyell in their Report to the Secretary of State for the Home Department concerning the Haswell Colliery Explosion in September 1844. They said : "In considering the extent of the fire "from the moment of the explosion, it is not to be supposed that firedamp was its "only fuel ; the coal dust swept by the rush of wind and flame from the floor, roof, "and walls of the works, would instantly take fire and burn if there were oxygen "enough present in the air to support its combustion ; and we found the dust "adhering to the faces of the pillars, props and walls in the direction of and on the "side towards the explosion, increasing gradually to a certain distance as we neared "the place of ignition.

"This deposit was in some parts half an inch, in others almost an inch thick ; it "adhered together in a friable coked state. When examined with the glass it "presented the fused round form of burnt coal dust, and when examined chemically "and compared with the coal itself, reduced to powder, was found deprived of the "greater portion of the bitumen, and in some instances entirely destitute of it

"There is every reason to believe that much coal gas was made from this dust in the "very air itself of the mine, by the flame of the firedamp which raised and swept it "along, and much of the carbon of this dust remained unburnt only from want "of air.

"At first we were greatly embarrassed by the circumstance of the large number "of deaths from chokedamp, and in the evidence that that had been present in very "considerable quantities compared with the small proportion of firedamp, which, in "the opinion of those in and about the works just before, must have occasioned the "explosion. But, on consideration of the character of the goaves and reservoirs for "gaseous fuel, and the effect of dust in the mine, we are satisfied that these "circumstances fully account for the apparent discrepancy."

At a subsequent discussion in January 1845 at the Royal Institution, Professor Faraday said :—

"The ignition and explosion of the (firedamp) mixture would raise and then "kindle the coal dust which is always pervading the passages, and these effects must "in a moment have made the part of the mine which was the scene of the calamity "glow like a furnace."

Little attention seems to have been directed to the subject until about 1870. Since then, Sir Frederick Abel, Professor W. Galloway, Messrs. W. N. and J. B. Atkinson (H.M. Inspectors of Mines), the Coal Dust Committees appointed by the North of England and Chesterfield Institutions of Mining Engineers, Messrs. Marecco, Morrison and Cochrane, Mr. H. Hall (H.M. Inspector of Mines) and Mr. Clark, Professor H. B. Dixon, Professor P. P. Bedson, and many others both in England and abroad have devoted considerable time to the elucidation of the question, and many conjectures have been formed as to the precise influence of coal dust in colliery explosions. A detailed history of this work is to be found in most English text books and throughout the technical literature of coal mining, so that it is unnecessary to recapitulate it.

The opinion of mining engineers and colliery officials differing as to the possible dangers of explosions of coal dust without the presence of even a small percentage of firedamp, a Royal Commission was appointed on February 9th, 1891, "to enquire "into the effect of coal dust in originating or extending explosions in mines, whether "by itself or in conjunction with firedamp ; and also to enquire whether there are "any practical means of preventing or mitigating any dangers that may arise from "the presence of coal dust in mines."

This Commission heard a large amount of evidence during the years 1891 to 1894, and published their Report in June of the latter year, summarising their conclusions as follows :—

"(1.) The danger of explosion in a mine in which gas exists, even in very "small quantities, is greatly increased by the presence of coal dust.

"(2.) A gas explosion in a fiery mine may be intensified and carried on "indefinitely, by coal dust raised by the explosion itself.

"(3.) Coal dust alone, without the presence of any gas at all, may cause a "dangerous explosion if ignited by a blown-out shot or other violent inflammation. "To produce such a result, however, the conditions must be exceptional, and are only "likely to be produced on rare occasions.

"(4.) Different dusts are inflammable, and consequently dangerous, in varying degrees; but it cannot be said with absolute certainty that any dust is entirely free from risk.

"(5.) There appears to be no probability that a dangerous explosion of coal "dust alone could ever be produced in a mine by a naked light or ordinary flame."*

The principal reasons for doubting the dangers of coal dust stated in the course of the evidence taken by this Commission, and expressed in their Second Report, were as follows :—

1. That the coal dust experiments had not represented practical conditions existing in the working of an ordinary mine. (p. xi.)

2. That the quantity of dust used in the experiments, where ignition of dust had been obtained, was excessive, the atmosphere being so thickly laden with dust that no living being could exist in it. (p. xi.)

3. That the experimental conditions necessary to carry complete conviction could only be obtained in the actual workings of a mine, in which case it would be practically impossible to observe the results of the explosions. The circumstances surrounding each experiment would be open to the same doubt as now surrounds accidental explosions occurring in the ordinary course of working. In fact, the information obtained from such experiments would not differ from that already available from the numerous disastrous explosions which had been investigated. (pp. xi. and xii.)

4. Considering the fact that 20,000,000 shots were fired in the United Kingdom in one year, and that a proportion were blown-out shots, it was singular that coal dust explosions did not occur almost daily, since experimental explosions could so readily be procured by blown-out shots in experimental galleries. (p. xii.)

5. That the practical immunity from explosions enjoyed for many years by the Somerset, Forest of Dean and West Durham collieries, representing non-fiery but dusty seams, was a proof that coal dust *per se* was not capable of being ignited by a blown-out shot. (p. xiv.)

6. It was definitely stated by some witnesses that "they had never known an "explosion of coal dust caused by a blown-out shot, and without the presence of "gas." And also "that even if an explosion could be set up, it would not be a "serious one, nor could it be carried far unless assisted by the presence of "firedamp." (p. xiv.)

It was suggested to the 1891 Commission that experiments on a large scale should be conducted, and the witness stated that the nearer the conditions of the experiments on the surface approached to those of a mine, the better it would bring home the information.†

From 1894 to 1906 many valuable papers were written on the subject and the belief in the danger of coal dust steadily but surely gained ground.

The present Royal Commission on Mines was appointed in June 1906, "to enquire into and report on certain questions relating to the health and safety of

* Second Report of Royal Commission on Explosions from Coal Dust in Mines, published 1894.

† Garforth. Answer No. 3779, Royal Commission on Coal Dust in Mines, 1891.

miners." Exhaustive evidence has been taken on the coal dust question, since conflicting opinions continued to be expressed by many leading mining engineers. In March 1907 the Commission decided to refer this particular question to a Committee of their own body, namely Lord Monkswell (Chairman), Sir Henry Cunynghame, Sir Lindsay Wood, Dr. J. S. Haldane, and Mr. Enoch Edwards, M.P. The Committee were asked to report as to what further experiments with coal dust were necessary, having regard to those already made in this country and elsewhere, and to prepare a scheme and estimate of the expenditure required for carrying out such experiments. An advisory body consisting of Captain Thomson (H.M. Chief Inspector of Explosives), Messrs. Henry Hall, I.S.O., and W. N. Atkinson (H.M. Inspectors of Mines), Professor H. B. Dixon (Victoria University, Manchester), Mr. W. E. Garforth (President of the Mining Association of Great Britain), and Professor W. Galloway (Cardiff), was associated with the Committee.

The Committee published a report of their deliberations, dated 30th April, 1907, stating that they were unanimously of the opinion that experiments on a large scale were required before the Commissioners could come to any decision on the points referred to, and they recommended that such experiments should be undertaken without delay.

After duly considering the respective merits of conducting the experiments in a portion of an abandoned mine, or in a specially-constructed gallery, in the form of a culvert partially sunk in the ground, made either of reinforced concrete or masonry, or in a wrought iron gallery built on the surface of the ground, they decided that the latter would give the best results. The main objections to using a portion of an abandoned mine were :—

(*a*) That most of those procurable for the purpose were naturally wet ;

(*b*) That there might be considerable danger in carrying on such work underground ;

(*c*) That it would be difficult to prove with absolute certainty that firedamp was not present ;

(*d*) That the recording of results would be almost impossible.

A wrought iron gallery built on the surface had many advantages over a reinforced concrete or masonry culvert, especially as it would be cheaper and easier to build, and would be structurally stronger. It would also afford more ready means of examination and could be more quickly and effectively repaired. With such a gallery, moreover, the observing and recording of the results of the experiments would be more easily accomplished.

The Committee were also of the opinion that " the gallery would have to be of " such a diameter that tram rails could be laid in it, and that lengths representing " any ordinary variety of mine road could be built up inside it. A diameter of " $7\frac{1}{2}$ ft., which is suggested by Mr. Garforth, seems to be suitable." This opinion was arrived at after examination of the photographs (figs. 1 and 2) submitted to the Committee of a gallery 78 ft. long, which had been erected at Altofts during the previous year for experimental work. These photographs showed the desirability of employing a wrought iron tube which would allow of experiments being conducted, using the same size of props and bars, the same gauge of tramline, the same size of tubs, the same area of roadway, and the same method of ventilation as in an ordinary

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FIG. 1.

FIG. 2.

Figs. 1 and 2.—Photographs submitted by Mr. Garforth to the Committee on Coal Dust Experiments (appointed by the Royal Commission of 1906).

underground roadway. The coal dust could also be distributed in a similar manner to that existing on a haulage road, and after an explosion the *débris* and destructive effects could be inspected in the same way as in recovering the roadways of a mine after an actual colliery disaster.

Plate I. illustrates some of the different galleries in which previous coal dust experiments have been made, and also galleries in which experiments are at present being conducted. These galleries or tubes have in no instance been of sufficient size to allow of the conditions prevailing in a mine being reproduced. Neither were they of sufficient length to obtain the development of explosive force, nor of sufficient strength to resist the latter if obtained. The inflammability of coal dust had been demonstrated by Faraday in 1845.

The Committee decided that a sum of £10,000 would be required to cover the cost of constructing a gallery such as had been proposed by Mr. Garforth, equipped with the requisite plant and scientific instruments, for the thorough investigation of the phenomena of coal dust explosions, provision being made for the cost of labour and material and various incidental expenses. They concluded their Report as follows :—" We consider it of the utmost importance that no time should be lost in " making the necessary preparations for the experiments proposed to be made for " the purposes of the Commission, and we suggest that the Government should be at " once asked to give their sanction for the experiments, and to consider ways and " means in regard to the provision of the necessary expenditure."

After two meetings had been held, negotiations extending over several months took place between the Government, Treasury, Royal Commission, and Mining Association, with a view to providing the necessary funds. The Government having decided that the Treasury could not subscribe the amount suggested as their share, the Mining Association agreed to carry out the experiments and to provide the sum of £10,000 by means of a levy on a tonnage basis, to which all the collieries in Great Britain connected with the Association subscribed. The coal owners also hoped that the proposed experiments would furnish indications which might lead to the discovery of some effective remedy, as an alternative to watering. Watering, though generally regarded as an efficient remedy, and largely adopted in Germany and America, is disadvantageous in many mines in this country owing to the effect that water has upon the strata composing the roof and sides of such mines.

A Special Committee, representative of the principal coalfields of Great Britain, was appointed to carry out the investigation. This Committee consisted of Sir Lindsay Wood (Northumberland, Durham and Cumberland), Mr. W. E. Garforth (Yorkshire, Staffordshire and Midland Counties), Mr. C. Pilkington (Lancashire and North Wales), Mr. J. T. Forgie (Scotland), and Mr. W. W. Hood (South Wales).

It was important that the site of the Experimental Station should be readily accessible from all parts of the United Kingdom. As Altofts, Yorkshire, was, owing to its central situation and good railway service, considered a suitable place, the Mining Association asked Mr. Garforth to undertake the personal supervision of the experiments. He then designed the present form of gallery, with relief valves, method of ventilation, &c. It was decided to erect the gallery in a field adjoining Messrs. Pope and Pearson's Collieries, as its construction would thereby be facilitated, and as the various colliery appliances demanded by the experimental work would be available, and a ready supply of steam, compressed air, and electricity could be obtained.

The investigation resolved itself under three heads :—

I. The demonstration of the explosive nature of a mixture of coal dust and air without the presence of inflammable gas.

II. The discovery of a preventive against, or remedy for, such explosions.

III. The investigation of the chemical and physical phenomena accompanying coal dust explosions.

PLATE I.

To face page 6.

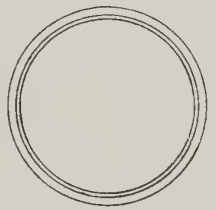
## DIAGRAM SHOWING SOME OF THE PRINCIPAL GALLERIES IN WHICH COAL DUST EXPERIMENTS HAVE BEEN CONDUCTED.

| Date. | Place. | Name. | Diagram of Gallery. | General Remarks. |
|---|---|---|---|---|

## GALLERIES IN WHICH EXPERIMENTS ARE AT PRESENT BEING CONDUCTED.

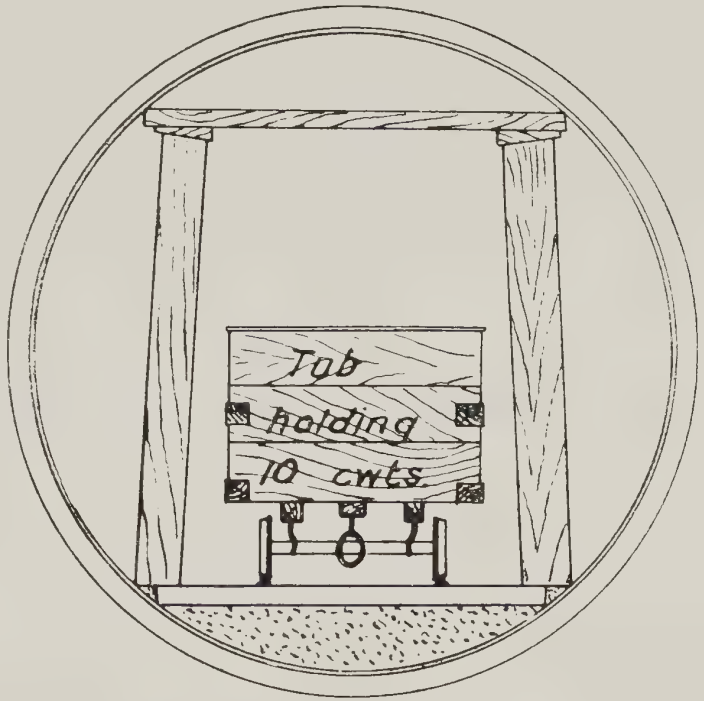
Liévin. FRANCE. 1907.

Diameter = 2 ft.
Length = 63 ft.



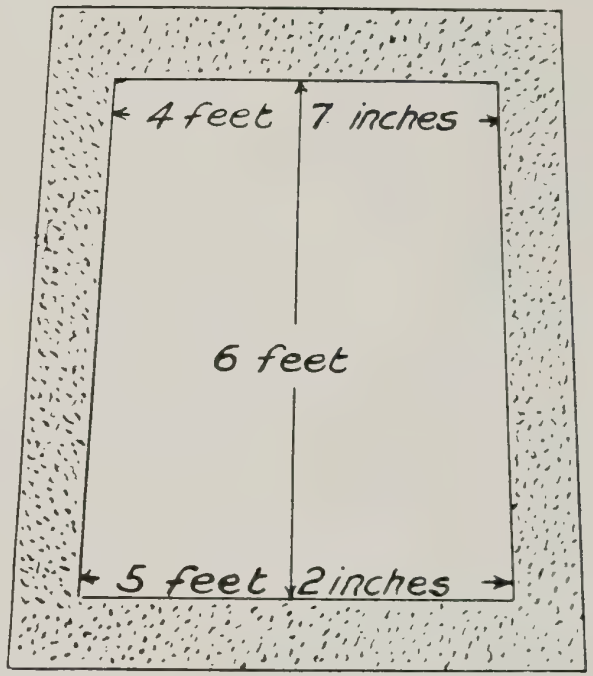
Gallery made of iron.

Altofts. BRITAIN. 1908.




Gallery made of iron and steel $7\frac{1}{2}$ ft. diameter.

Liévin. FRANCE. 1908.




Gallery made of reinforced concrete.

# DIAGRAM SHOWING SOME OF THE PRINCIPAL GALLERIES IN WHICH COAL DUST EXPERIMENTS HAVE BEEN CONDUCTED.

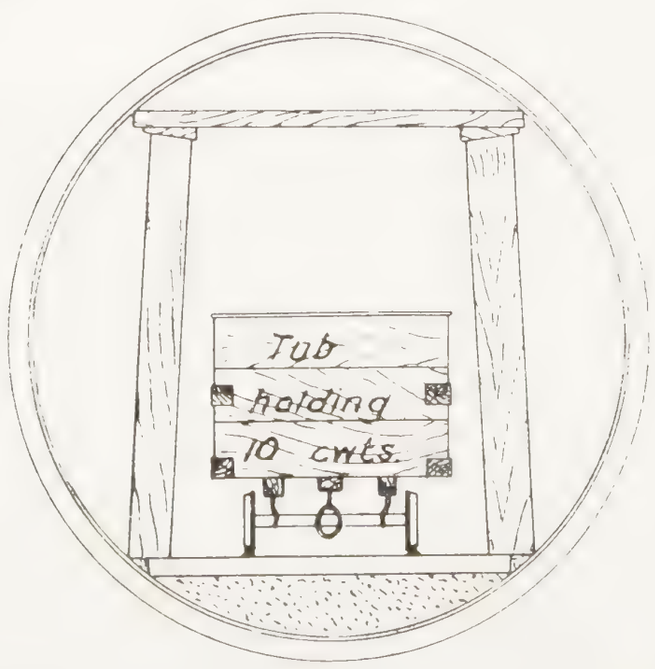
| Date. | Place. | Name. | Diagram of Gallery. | General Remarks. |
|---|---|---|---|---|
| 1803 | Britain | Buddle | Wallsend Colliery Explosion, September 1805. | "The workings were very dry and dusty and the survivors who were the most distant from the point of explosion were burnt by the shower of red-hot sparks of the ignited dust which were driven along by the force of the explosion." |
| 1845 | Britain | Faraday | Lecture at Royal Institution | Showed by experiment at a lecture at the Royal Institution, London, on January 17th, 1845, that by taking coal dust and adding it to a flame, there was a marked difference in the combination as compared with a flame without dust. |
| 1875 | France | Vital | o | Glass tube—<br>Length = 6 ft. 7 in.<br>Diameter = 1·38 in. |
| 1875 | Britain | Galloway | | Gallery made of wood—<br>Length = 18 ft. 9 in.<br>Width = 6 in.<br>Height = 1 ft. |
| 1876 | Britain | Hall and Clark | Adit 135 ft. long, going from the surface at the crop of a coal seam. | |
| 1878 | Britain | Marreco, Morrison and Cochrane | | Gallery made of wood—<br>Length = 24 ft.<br>Width = 6 in.<br>Height = 1 ft. |
| 1879 | Britain | Chesterfield Institute | | Gallery made of wood—<br>Length = 82 ft.<br>Width = 1 ft. 4 in.<br>Height = 1 ft. 6 in. |
| 1880 | Britain | Galloway | | Gallery made of wood—<br>Length = 126 ft.<br>Width = 2 ft.<br>Height = 2 ft. |
| 1884 | Germany | Prussian Commission | | Gallery made of wood and strengthened with iron bands.<br>Axes = 5 ft. 8 in. and 3 ft. 11 in.<br>Length = 167 ft. 3 in. |
| 1890 | Britain | Hall | Experiments in a shaft 8 ft. diameter and 630 ft. deep. (Third series.) | |
| 1893 | Britain | Hall | Experiments in a shaft 7 ft. diameter and 150 ft. deep. (Fourth series.) | |

## GALLERIES IN WHICH EXPERIMENTS ARE AT PRESENT BEING CONDUCTED.

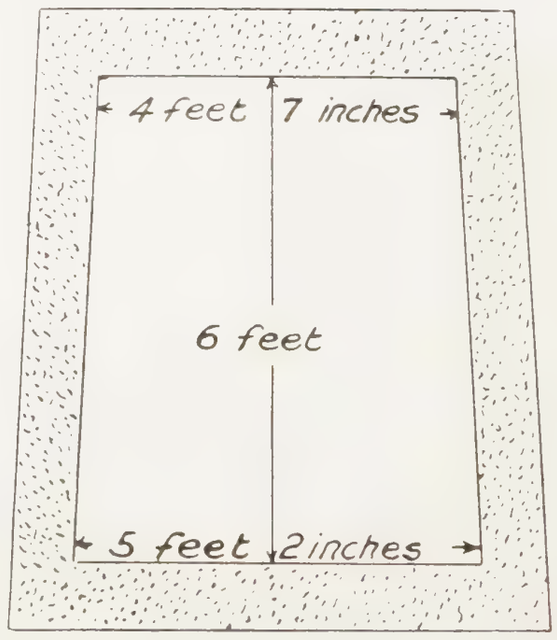
| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Liévin. | France. | 1907. | Altofts. | Britain. | 1908. | Liévin. | France. | 1908. |

Diameter = 2 ft.
Length = 63 ft.

Gallery made of iron.




Gallery made of iron and steel 7½ ft. diameter.




Gallery made of reinforced concrete.

## CHAPTER II.

# THE EXPERIMENTAL GALLERY

AND THE

# METHOD OF CONDUCTING EXPERIMENTS.

CHAPTER II.

# THE EXPERIMENTAL GALLERY AND THE METHOD OF CONDUCTING THE EXPERIMENTS.

In determining the method of conducting the experiments that would be necessary to demonstrate conclusively the fact that coal dust, when raised as a cloud in air and ignited, can, in the complete absence of firedamp, propagate flame with explosive violence, the following factors had to be considered :—

1. The gallery, representing the roadway of a mine, had to be of such dimensions as would allow of the requirements mentioned in the Introduction being carried out. It had also to be of sufficient strength to withstand a high pressure, and to be capable of being quickly repaired at a reasonable cost.

2. An air current had to be maintained in the gallery similar in quantity to that ordinarily met with on the main roads of a mine, with such a margin of extra ventilation as the experimental work might demand.*

3. The coal dust had to be distributed within the gallery in quantity corresponding with that usually present on an underground haulage road ; any pack walls or shelves, which might be required to accommodate the dust, had to be quickly and cheaply replaceable if damaged or destroyed by the explosion.

4. To ignite the dust, a flame had to be produced similar to that given by a blown-out shot or by the explosion of a gaseous mixture.

## THE GALLERY.

Instructions to proceed with the work were received about the middle of February 1908. With a view of placing as early as possible reliable information before the coal owners and their officials, it was decided to construct the gallery of second-hand boiler shells, which could be procured immediately, instead of waiting for the delivery of specially-made tubes. By doing this, the gallery was completed by May, and advantage was taken of the long and warm days of the summer and autumn of 1908, instead of delaying the actual experimental work until the following year. It was realised that no work could be done during the winter months, owing to fog and other adverse atmospheric conditions.

As the extent of the pressure that might be set up by a coal dust explosion was unknown, it was considered that the circular form of tube should be adopted, as that construction provided the greatest strength with the largest sectional area, and

* The quantity of air passing on the West Haulage Road in the Silkstone Seam at Altofts, when the explosion occurred in 1886, was 47,000 cubic feet per minute.

admitted of being further strengthened if required by circular hoops of T-iron or by continuous laps of chain (figs. 3 and 4).*

The main tube or intake (Plate II., fig. i.) is 7 ft. 6 in. in diameter, the shells varying in length from 24 to 30 feet. They are principally of wrought iron, $\frac{7}{16}$ in. thick, though some are of steel, and were procured from various parts of the country after having been examined and approved by an engineer connected with the colliery staff.† The shells were placed in position by means of a steam travelling crane loaned by the colliery, and were attached to each other by angle iron hoops marked in position and drilled to allow for any slight differences between the diameters of some of the shells.

The joints between the shells were intentionally not made perfectly tight, in order to diminish the risk of bursting the gallery. They were, however, made sufficiently tight, by the insertion of rings, so as not to leak with low pressures.‡

This intake was laid down in one straight length without branch roads, but arrangements were made to enable breeches-pieces to be inserted to provide such branches if required. The intake can be easily lengthened or shortened for different experiments.

The return gallery, made of boiler shells 6 ft. in diameter, constructed of $\frac{3}{8}$ in. plates, has a total length of 295 ft. As will be seen from the plan (Plate III.), it is zigzag in form, with four right-angle bends measuring respectively 158, 32, 59 and 28 feet. Each bend carries two relief valves to protect the ventilating fan from injury: these valves were designed to give, on the principle of the Joseph Dickenson anemometer (Plate II., fig. ii.), some idea of the pressure developed by the angle to which they would be opened by the force of the explosion.

After the boiler shells had been placed in position, the various manholes and other openings were covered with suitable blank flanges of iron. The tubes were tarred externally to protect them against corrosion. Owing to the evenness of the field, only a slight excavation was necessary to allow the whole length of the gallery to rest in a horizontal position. The earth-work, banked against the sides of the gallery, tends to prevent vibration.

The junction-piece (Plate II., fig. iii.), was specially designed of $\frac{1}{2}$ in. plates, with four openings, two of which form the connections for the intake and return, the other two being fitted with explosion doors made of wood the thickness of which was progressively increased from $\frac{3}{4}$ in. to 3 in. These doors have usually been blown out by the force of the explosion—No. 9 more frequently than No. 10.

* A rectangular gallery 7 ft. high and 6 ft. wide, made of $\frac{1}{2}$ in. plates strengthened by T-iron or H-iron strips, would have cost more than double that of a new wrought iron circular tube. In addition, the relative strength of the square section would be much less than that of the circular section. A rectangular gallery would not admit of easy repair in case of rupture, and could not be cleaned so easily. On completion of the experiments there would have been no sale for the plates, as they would have been pierced with the rivet holes of the stiffeners and would be too large (15 ft. × 7 ft.) for flat sheets without being cut. There is usually a sale for second-hand boiler shells.

† The following information may be of interest regarding the strength of such boiler shells:—Experimental tests, carried out during the years 1874-6, on an iron boiler 7 ft. in diameter and 30 ft. long, made of $\frac{7}{16}$ in. plates lap-jointed longitudinally, showed the actual bursting pressure to be 275 lb. per square inch, the calculated pressure, based on the Board of Trade formula, being the same. With double-riveted lap-joints the actual bursting pressure was 310 lb., and the calculated pressure 315 lb. per square inch. The ruptured joints of portions of the boiler may be seen in the Museum of the Manchester Steam Users' Association.

‡ It was recognised that a smaller gallery would be necessary if it were decided to investigate explosions of great length involving perhaps the setting up of what is termed the "detonation wave."

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Fig. 3.—Downcast End of Gallery

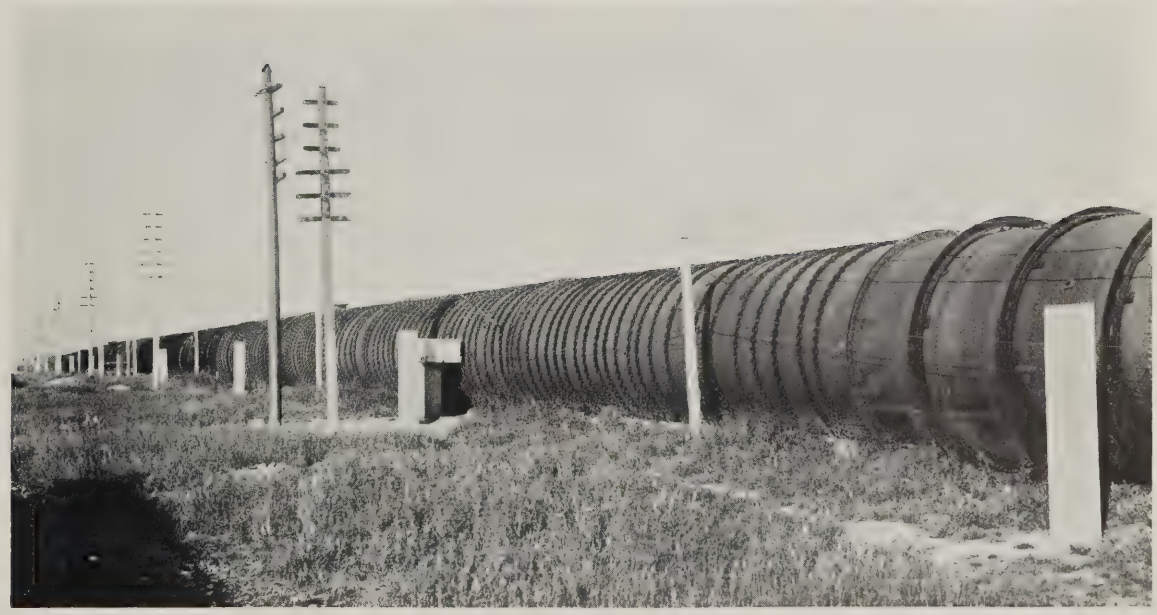


Fig. 4.—Continuation of Intake, showing Strengthening Hoops and Chains.

With a view of preventing this and thus lessening the cost of repairs, a cone piece 10 ft. long (Plate II., fig. iii.), made of $\frac{1}{2}$ in. boiler plates, has been attached to the junction piece, thereby reducing the area of the explosion door presented to the force of the blast, from 44 square feet to 22 square feet, and the door is now only blown out with high pressures. The distance to which these and other relief doors have been blown has given an approximate idea of the force developed, and they have thus answered this further purpose.

## THE INTERIOR ARRANGEMENT OF THE GALLERY.

The intake has a level floor, 5 ft. wide, made of concrete, and a line of rails with 25 in. gauge, laid on sleepers set in the concrete every 3 ft., runs the whole length. This tramline is of service in transporting material from one part of the gallery to another (Plate II., fig. iv.).

In order to conform to the idea of making the inside of the gallery like the roadway of a mine, it had been suggested that the sides of the tube should be thickly plastered with cement in order to present a rough surface, but this would have interfered with the cleaning of the gallery (necessary after every experiment), and would have required constant renewal. Props and bars are, however, set at regular intervals to represent the timbering in a mine: these props afford valuable information as to the intensity of the explosion, since the position of those that are displaced is recorded, each prop being numbered by small iron "motties," such as are used by miners for numbering their tubs. To obtain information regarding the deposit of coke and dust, and with a view of submitting them to microscopical examination, some of the sets of timber are securely fixed in position by iron clamps (Plate II., fig. iv.).

In the first gallery that was constructed in 1906 (figs. 1 and 2), pack walls were built of loose stones in order to provide ledges on which the coal dust could rest. This arrangement, however, rendered the gallery difficult to clean, and entailed heavy cost of labour in building, besides being open to the danger of allowing loose stones to be projected from the gallery by an explosion. It was therefore decided instead to place thin wooden shelves longitudinally on which the dust could be spread: five such rows of shelves, 5 in. wide and $\frac{3}{4}$ in. thick, are fixed on each side of the gallery, supported on iron brackets and extending the whole distance required for the experiment. The shelf surface presented is intended to correspond to that of the ledges and interstices of the pack walls at the sides of an underground roadway. This arrangement of shelves allows a smaller or greater quantity of coal dust to be spread without any expensive alterations.

## THE AIR CURRENT.

The ventilating current is produced by a "Sirocco" fan capable of passing 80,000 cubic feet of air per minute with a water gauge of 3 in. The quantity of air passing through the gallery with various speeds of the fan is ascertained by means of a Casartelli anemometer. The fan is enclosed in a sheet steel casing and is connected to the return by a fan drift (28 ft. long, by 7 ft. 6 in. high and 5 ft. wide), made of $\frac{1}{2}$ in. steel plates.

Two wooden doors, each 6 ft. 9 in. high by 3 ft. 5 in. wide, hang by horizontal hinges at either end of the fan drift (Plate II., fig. v.). In addition to these doors

there are two other openings; an extension piece (Plate III., 1), and an additional door (Plate III., 2). The extension piece is closed by a blank flange of wood 1 in. thick, the wood being bolted through to the flange of the tubing. The additional door 2 is closed by a blank flange of wood $1\frac{1}{2}$ in. thick secured to the T-iron uprights of the fan drift.

With a view of retaining the afterdamp resulting from an explosion, a supplementary door is placed between the fan drift and the adjoining section of the return. This door is suspended from a horizontal hinge and normally is held by a catch against the flat roof of the fan drift.

The *evasée* chimney is constructed of light boards, which, being easily displaced, give an indication of the extent of the force of the explosion or of the "after-suck" towards the return.

The engine that drives the fan is capable of developing 85 I.H.P., the cylinder being 18 in. in diameter with a stroke of 2 ft. 9 in. The flywheel is 12 ft. in diameter, and the fan pulley 2 ft. 3 in. in diameter, the drive being transmitted by a belt 12 in. wide.

## THE COAL DUST.

In order to produce comparable results in different experiments, it is necessary that the coal dust should be of a uniform degree of fineness and dryness.

In the first series of experiments it was decided to use dust from the Silkstone Seam at Altofts, since dust from this seam was known to have caused an explosion attended by the loss of twenty-two lives, entailing serious damage.* Its use is particularly interesting, since samples of the dust were collected from the roadways after this explosion (in 1886). They were afterwards subjected to microscopical examination,† and from the slides which have been preserved a comparison can be made with samples taken in the gallery explosions of 1907-9.

In order to provide a sufficient quantity of dust for the large number of demonstrations that were made, it was, in the earlier experiments, collected at the screens of the Silkstone Pit, since it was found impossible to collect enough from the underground workings.

As the experiments increased in number and magnitude, the supply of dust from the screens proved insufficient. A disintegrator was therefore installed (fig. 5), and the dust used from Experiment No. 24 up to the present time has been made by pulverising nut coal. The dust produced in this way contains a smaller percentage of ash than screen dust, the average analysis and degree of fineness of that obtained from Silkstone coal and dust from the screens at the Silkstone Pit being :—

Chemical Analysis.

| | Screen dust. | Dust from pulveriser. |
|---|---|---|
| | Per cent. | Per cent. |
| Moisture | 4·42 | 3·21 |
| Volatile matter | 24·75 | 33·68 |
| Fixed carbon | 62·99 | 57·60 |
| Ash | 7·84 | 5·51 |

* Altofts explosion, 1886.

† First Report of the Royal Commission on Explosions from Coal Dust in Mines, 1891, Appendix XII.

To face page 12

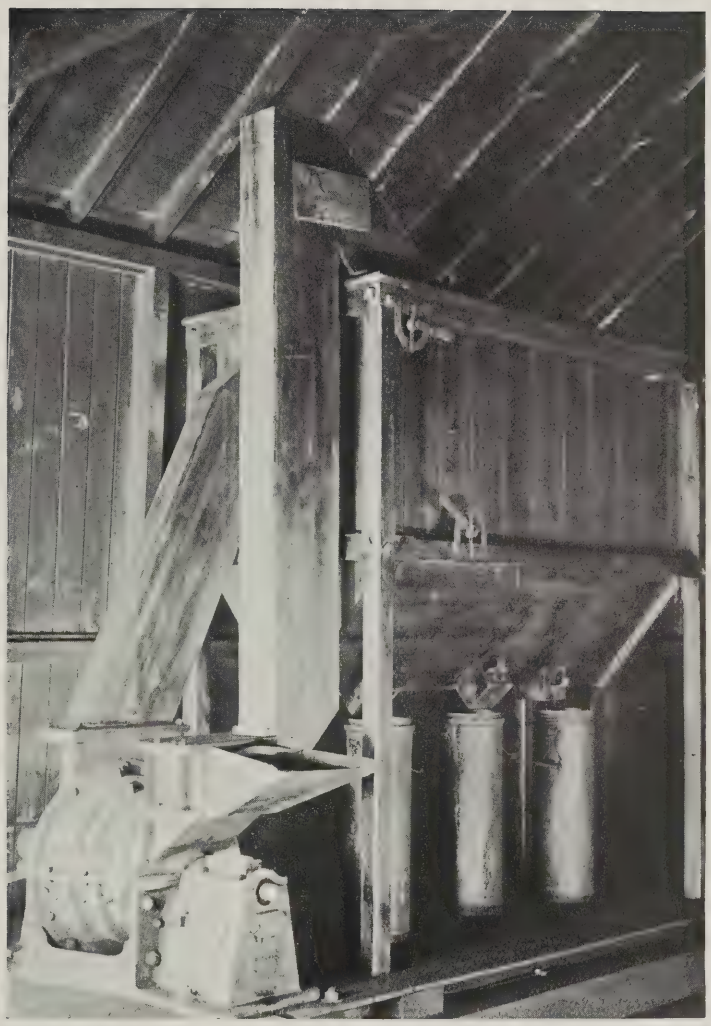


Fig. 5.—Pulveriser, Collecting Hoppers, and Cases in which Coal Dust is carried into the Gallery.

Degree of Fineness.

| | Screen dust. | Dust from pulveriser. |
|---|---|---|
| | Per cent. | Per cent. |
| Remaining on 100 mesh | *Nil* | 7·25 |
| Through 100 on 150 | *Nil* | 7·50 |
| ,, 150 on 200 | *Nil* | 3·00 |
| ,, 200 on 240 | 0·3 | 9·25 |
| ,, 240 and finer | 99·7 | 73·00 |

Although dust from the roadways of the mine has not been used for the experiments, it is interesting to note its chemical composition and fineness. Samples collected over a length of 30 yards of the main haulage road in the Silkstone Pit gave the following results :—

Chemical Analysis.

| | Dust from floor. | Dust from sides (3 ft. from floor). | Dust from bar tops. |
|---|---|---|---|
| | Per cent. | Per cent. | Per cent. |
| Moisture | 8·12 | 9·05 | 7·87 |
| Volatile matter | 25·10 | 22·40 | 20·30 |
| Fixed carbon | 40·24 | 39·95 | 35·93 |
| Ash | 26·54 | 28·60 | 35·90 |

Degree of Fineness.

| | Dust from floor. | Dust from sides (3 ft. from floor). | Dust from bar tops. |
|---|---|---|---|
| | Per cent. | Per cent. | Per cent. |
| Remaining on 100 mesh | 47·3 | 6·2 | 1·7 |
| Through 100 on 150 | 17·1 | 4·1 | 1·3 |
| ,, 150 on 200 | 1·9 | 0·1 | 0·8 |
| ,, 200 on 240 | 6·7 | 6·9 | 5·1 |
| ,, 240 and finer | 27·0 | 82·7 | 91·0 |

The quantity of dust used is generally 1 lb. per linear foot of the gallery : this works out at 0·39 ounce per cubic foot of air space. This amount is admittedly less than that frequently met with on some underground roads,* but it was recognised that it would be better that this should be so than that an excessive amount of dust should be used. On the other hand it was thought more important in the first instance to make sure of demonstrating the fact that coal dust was explosive than to spend time in determining the minimum density of dust cloud which would allow flame to be propagated.

## THE MEANS OF IGNITION.

Ignition of the dust is effected by the firing of a charge of blasting powder from a cannon, representing a blown-out shot ; blasting powder is used, since many of the greatest mine disasters on record have been traced to blown-out shots of this explosive. In the experiments conducted by Captain Desborough at Woolwich, ignitions of coal dust have been obtained with permitted explosives, but only in a

* It has often been remarked by visitors that the quantity of dust in the gallery was much less than that existing on the roads at their own collieries.

small percentage of the trials. The fact that ignitions of coal dust could, under certain conditions, be obtained with some, if not all, "permitted explosives," was incontestably proved.* It was decided to accept this fact as granted for the time being, since the study of the phenomena of coal dust explosions, and the finding of an adequate remedy other than watering, were deemed of greater importance than the question of ignition.

The cannon or "igniter" is made of a special quality of wrought iron and is 3 ft. long by 6 in. in diameter with a 2 in. bore 2 ft. 9 in. deep.† It is charged with 24 ounces ‡ of powder with 8 in. of dry clay stemming properly rammed, and is fired against the air current with the bore inclined upwards at an angle of from 32 to 35 degrees (fig. 6).

The photographs on Plate IV. show the length of flame obtained when different charges of powder, stemmed as above, are fired from the cannon. To obtain this series of photographs the same quality of powder was used as in the experiments.

Successful ignition of the dust and propagation of the explosion are nearly always obtained by the firing of this igniter alone; when, however, the convenience of visitors coming from long distances to witness a demonstration had to be studied, efforts had to be made to obtain as high a percentage of successful results as possible, in order to prevent disappointment. A second small cannon, or "cloud raiser," is therefore introduced for the purpose of ensuring the presence of a cloud of dust at the moment of firing the igniter. This small cannon measures 2 ft. long by 9 in. in diameter, with a $1\frac{3}{4}$ in. borehole, 8 in. deep. It is placed at a distance of 90 ft. from the igniter, nearer the downcast end, and is charged with only 4 ounces of gunpowder with 3 in. of clay stemming. To prevent the cloud raiser igniting the dust, it is placed pointing towards the side of the gallery, and no coal dust is strewn near it (fig. 7).

The manner in which the demonstrations are carried out is as follows :—

When the coal has been ground, the dust is emptied from the hoppers of the pulveriser into dust-tight cases containing about 30 lb. each. These cases are carried into the gallery and the dust evenly spread by hand on the floor, shelves and timber over the desired length. The usual length adopted for demonstrations has been 275 ft. The cannons are charged. The fan is started, the doors in the fan drift being wide open, and its speed increased until the correct volume of air is being passed. The doors are then closed by means of a series of levers and cords controlled from the firing station (fig. 8). The act of closing the doors completes an electric circuit, which rings a bell inside the firing station; at the same time a seconds clock is started. Seven seconds after the closing of the fan doors the cloud raiser is fired, and the igniter is fired two seconds later. The flame from the latter produces the explosion. Both these cannons are fired electrically (fig. 9).

Special precautions are taken to safeguard the operators and other persons engaged near the Experimental Station. Ten minutes before the experiment a steam whistle is sounded to warn the neighbourhood that an explosion is about to take

* *See* Report on Experiments with Coal Dust, carried out at the Home Office Testing Station at Woolwich, by Captain A. H. P. Desborough (H.M. Inspector of Explosives), published 1907.

† It was originally intended to construct a cannon of sufficient bore to allow of an internal lining composed of the ripping stone overlying the Silkstone Seam at Altofts, but there were practical difficulties in the way of providing such an arrangement, and the flame from an ordinary cannon was found to answer the purpose.

‡ In the earlier experiments 40 ounces of gunpowder were used.

To face page 14.

Fig. 6.—Interior of Intake, looking towards Return showing position of large Cannon or Igniter, shelves on which Coal Dust is laid, and tufts of Cotton Wool for determining length of Flame.

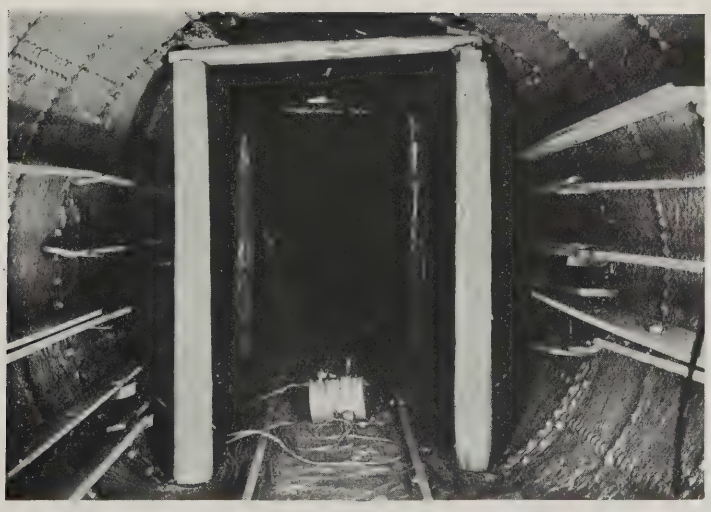


Fig. 7.—Position of small Cannon or Cloud-Raiser.

Fig. 8.—Exterior of Firing Station.

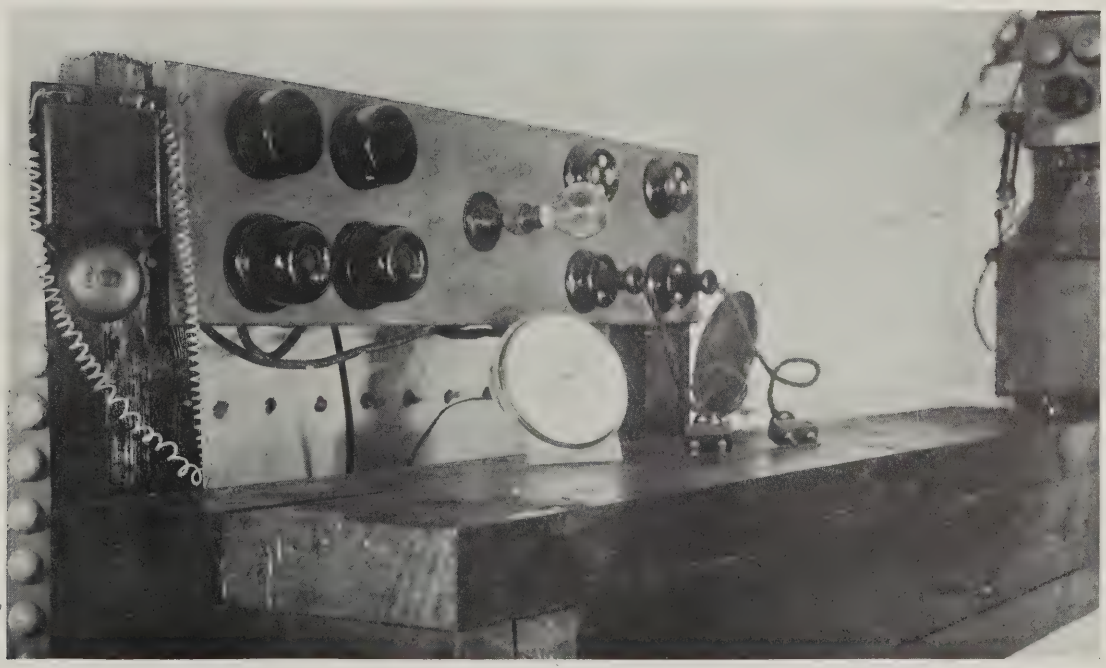


Fig. 9.—Part of the Interior of the Firing Station showing the general arrangement for Firing the Cannons.

place. Specially-appointed men then form a cordon round the gallery at a distance of about 200 yards. Two minutes before firing, the whistle is again blown, when each signalman substitutes a white flag for the red one previously hoisted, thus signifying that all is clear ; whereupon the cannons are fired.

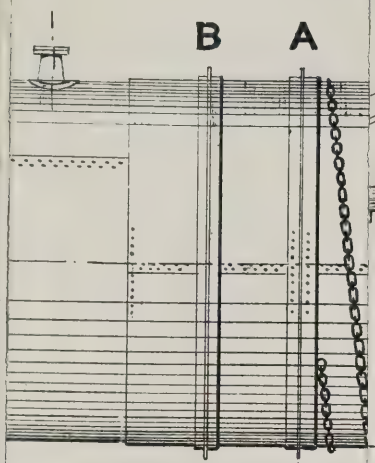
The Committee take this opportunity of thanking the tenants of houses in the neighbourhood for the considerate way in which they have borne the inconvenience consequent on the proximity of the Experimental Station.

It may be mentioned that during the past two years no important alterations have been made in the original design and construction of the gallery, and that no expense has been incurred in this direction. The gallery and accessories have, with one important exception* (when valuable information was obtained), successfully resisted the great explosive pressure developed during 116 experiments. The Committee are pleased to be able to state that not a single accident or injury to persons engaged in conducting or witnessing the explosions has occurred. The arrangement of the tubes has enabled many different experimental methods to be employed, and the position of the gallery in relation to the railway embankments has allowed of a large number of visitors at one time witnessing the evidences of the force developed by an explosion of coal dust without the presence of gas.

* Experiment No. 25, which is described in detail on pages 31 to 34.

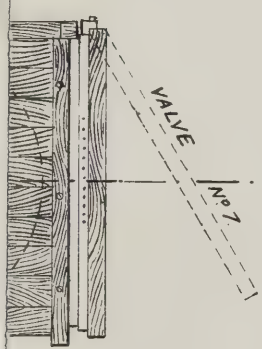
# PLATE II.

## Gallery.

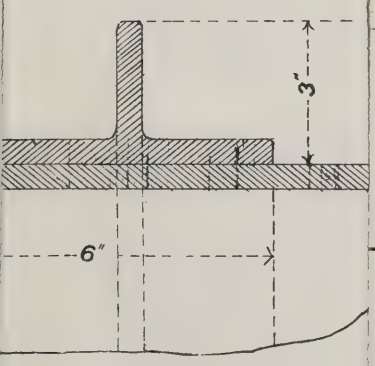



(Fig i.)

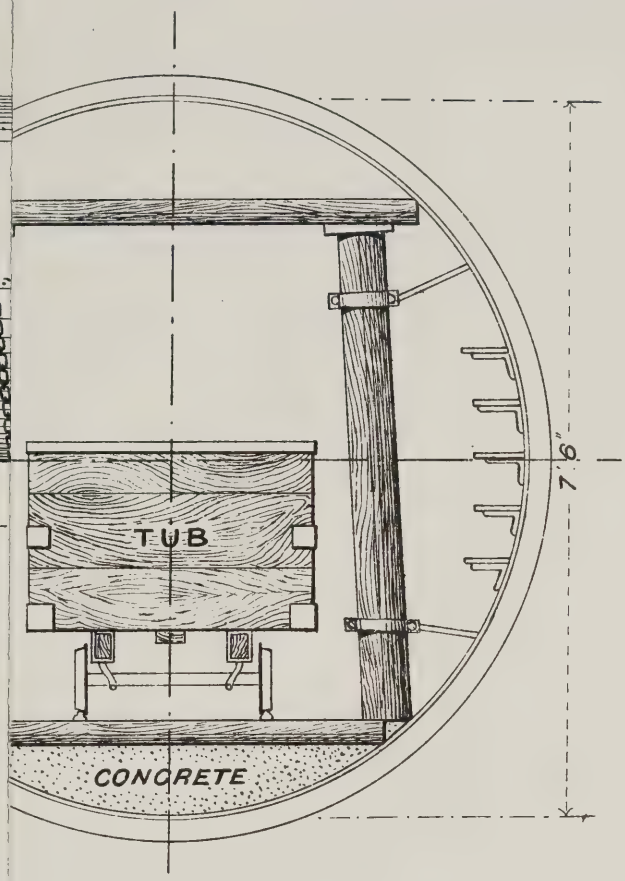
## 7 & 8.



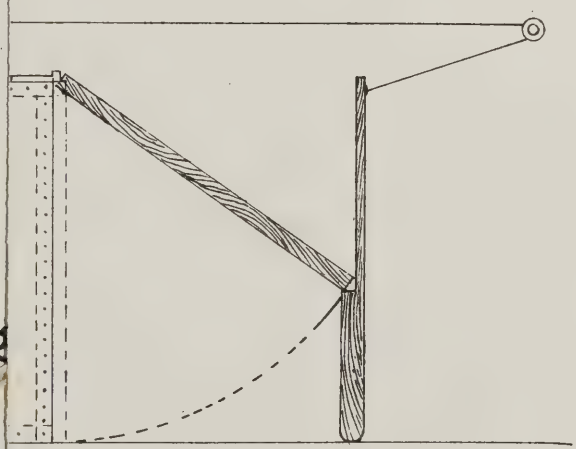

## strengthening Ring




## Mouth of Main Gallery.

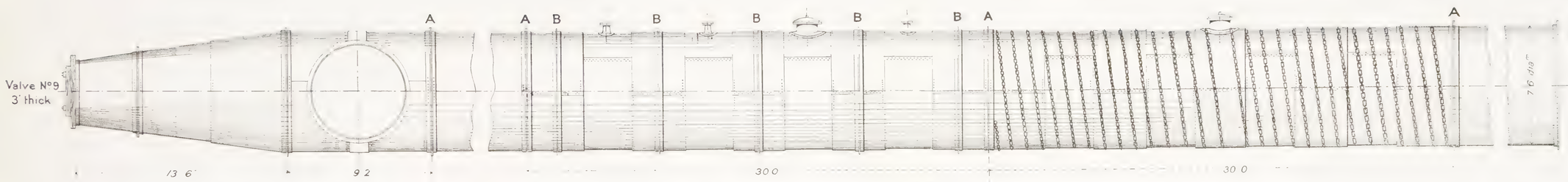



(Fig iv.)



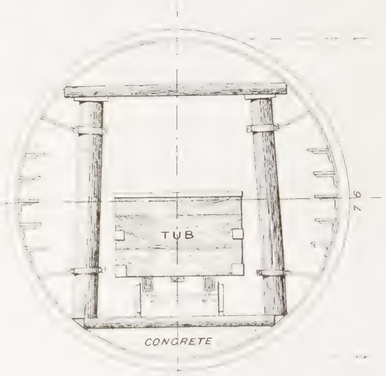
## Experiment.

## Elevation of Portion of Main Gallery.




(Fig i.)

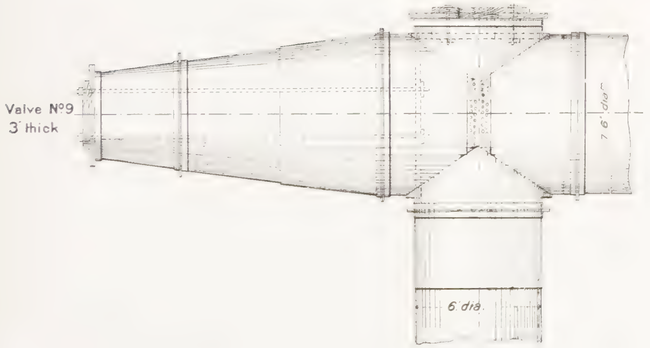
## End view of Mouth of Main Gallery.




(Fig iv.)

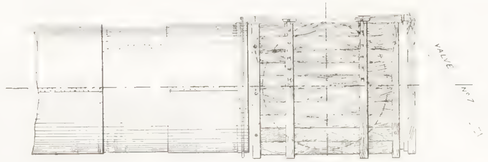
## Valve N° 10. 3" thick.

*Strengthened by 3 baulks of Timber 8" square placed inside.*



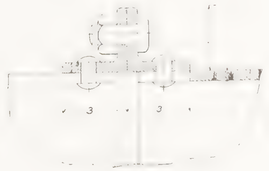

(Fig iii.)

## Section of Safety Valves N°s 7 & 8.



(Fig ii.)

## Section of Joint at A.



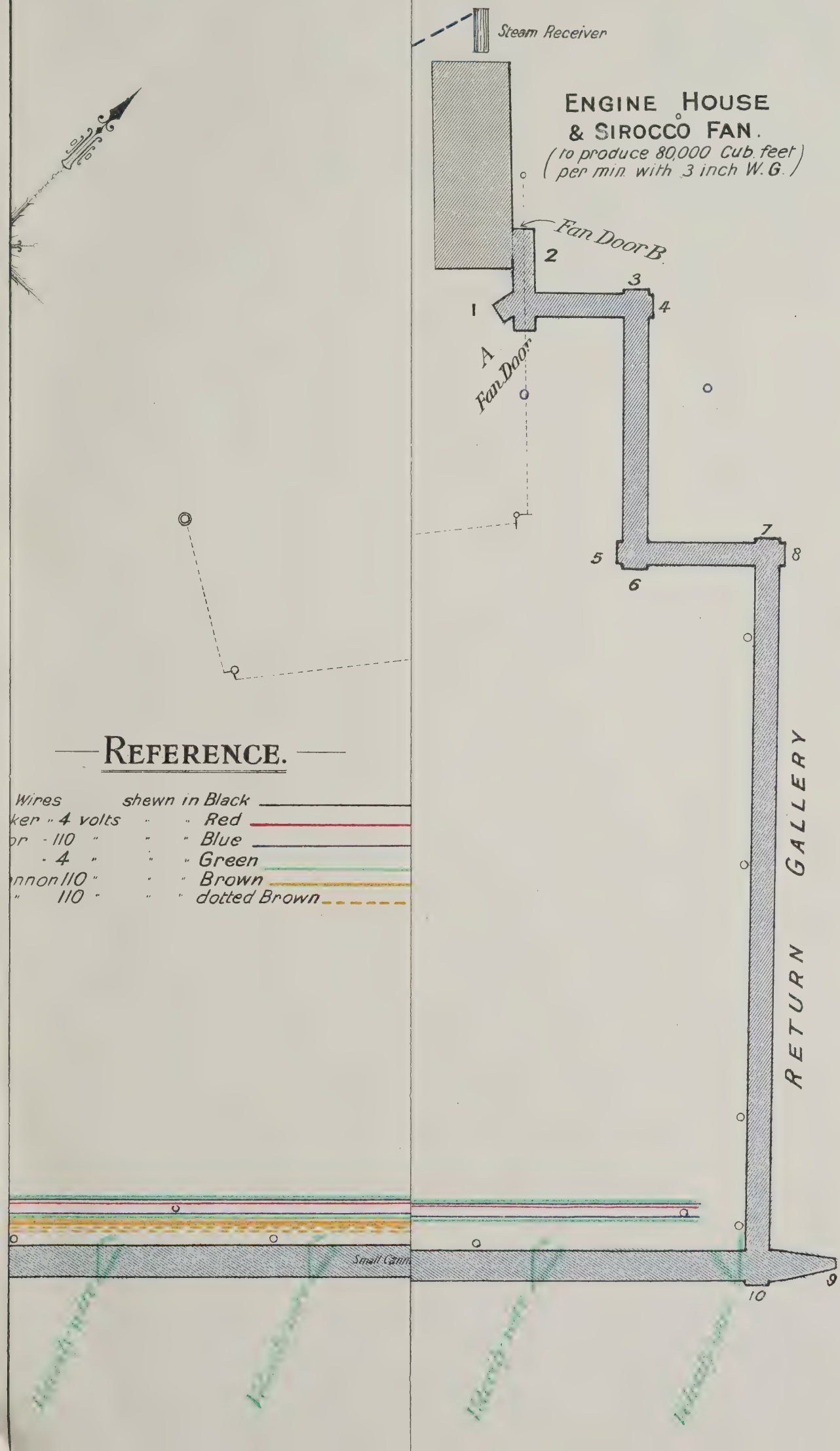

## Section of strengthening Rings at B.

(Fig v.)

Section shewing how Fan Doors can be closed before Experiment.

Plan shewing Junction of Main Gallery and Return Gallery.

# ATE III.




## REFERENCE.

| | | |
|---|---|---|
| Wires | shewn in Black | |
| ker " 4 volts | " " Red | |
| or " 110 " | " " Blue | |
| " 4 " | " " Green | |
| nnon 110 " | " " Brown | |
| " 110 " | " " dotted Brown | |

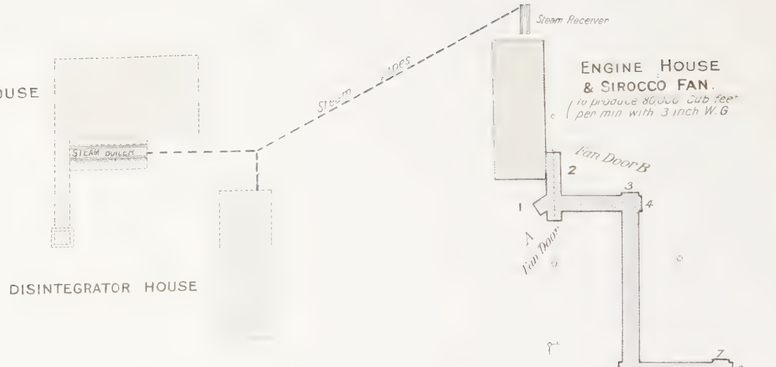
PLATE III.

# BRITISH COAL DUST EXPERIMENTS.

## KEY PLAN.

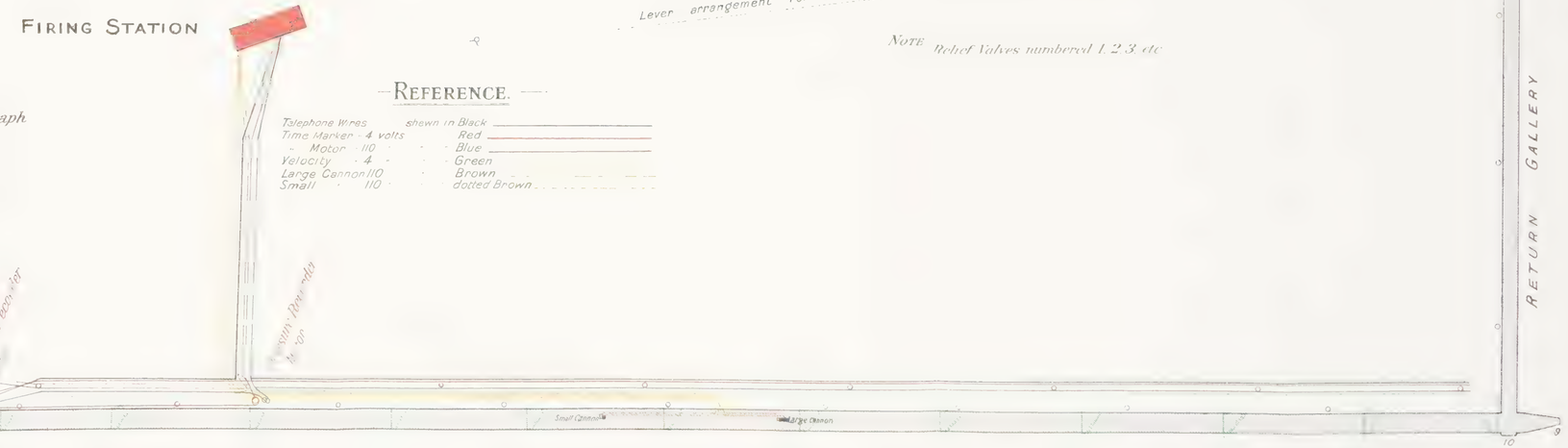
— Scale of Feet —

10 5 0 10 20 30 40 50 60 70 80 90 100



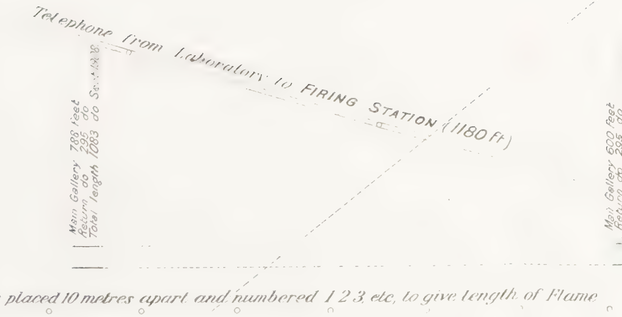

Lever arrangement For closing Fan Doors from Firing Station

NOTE Relief Valves numbered 1 2 3 etc




### REFERENCE.

| | | |
|---|---|---|
| Telephone Wires | shewn in Black | |
| Time Marker - 4 volts | - | Red |
| - Motor - 110 | - | Blue |
| Velocity - 4 - | - | Green |
| Large Cannon 110 | - | Brown |
| Small - 110 | - | dotted Brown |


Telephone from Laboratory to FIRING STATION (1180 ft)
Main Gallery 700 feet
Height 6 ft 3 ins
Area 78 sq ft
Perimeter 28.85 ins
Total length 1063 ft

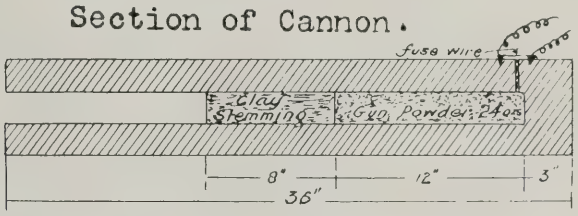
Posts placed 10 metres apart and numbered 1 2 3 etc, to give length of Flame

# LENGTHS OF FLAME

obtained by

## FIRING DIFFERENT CHARGES OF BLASTING POWDER

from a cannon stemmed with eight inches of clay.

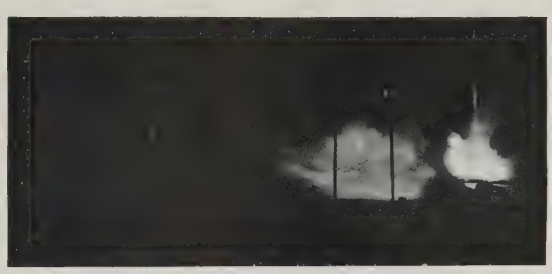



NOTE.— The black lines shown in the photographs are poles fixed three feet apart.

Charge = 4 oz.

Length of Flame = 9 feet.

Charge = 8 oz.



Length of Flame = 9½ feet.

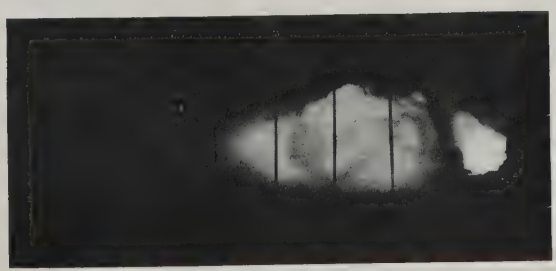
Charge = 12 oz.

Length of Flame = 10 feet.

Charge = 16 oz.

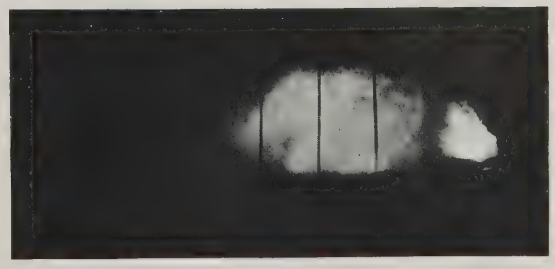
Length of Flame = 10½ feet.

Charge = 20 oz.



Length of Flame = 12½ feet.

Charge = 24 oz.



Length of Flame = 11 feet.

## CHAPTER III.

# THE EXPLOSIVE NATURE OF COAL DUST WHEN RAISED AS A CLOUD IN AIR.

CHAPTER III.

## THE EXPLOSIVE NATURE OF COAL DUST WHEN RAISED AS A CLOUD IN AIR.

As has already been stated in the Introduction, one of the most important objects of this enquiry has been to demonstrate as conclusively as possible the great danger that exists from the presence of fine coal dust on the roadways of a mine; and, by ensuring the absence of inflammable gas in the Experimental Gallery, to definitely establish the fact that it is not essential that firedamp in addition to coal dust should be present for an explosion to be propagated.

The Committee therefore decided, as soon as experiments had shown the manner in which the explosions could be demonstrated most effectively, to devote the greater part of the summer of 1908 to this purpose.

Demonstrations have been given to more than eight hundred coal owners, colliery officials, inspectors of mines and scientific men from all parts of the United Kingdom, from India and South Africa, and from France, Germany and America; and it is now admitted by all who have witnessed the experiments, that the danger of coal dust has been definitely proved, and that the controversy which has existed for more than a quarter of a century has been finally set at rest.*

Before recording the details of some of the typical experiments, it may be useful to give a general description of the principal facts that are observed during the course of a demonstration.

The chief endeavours have been directed towards reproducing, as far as possible, the conditions of a main intake or haulage road, with the object of noting to what extent the effects recorded during exploration work after a colliery disaster are reproduced by an artificial explosion. In describing the phenomena observed during an experiment, therefore, it will be of interest to draw a comparison.

When the cloud raiser is fired, a jet of dust, 4 or 5 feet long, is puffed out from the downcast end, against the normal direction of the air current. From this it may be concluded that the ventilating current is momentarily arrested and that the concussion caused by the firing of the 4 oz. of blasting powder raises in suspension in the air current a certain proportion of the dust, which then carries it towards the return. The amount of dust thus carried past the point of ignition cannot be determined exactly, so that for the purposes of comparison between one experiment and another, the length of flame behind the point of ignition has not been

* Among the visitors responding to the invitation to witness the demonstrations were the late Lord Monkswell, Sir Henry Cunynghame, Dr. J. S. Haldane, Mr. Ratcliffe Ellis, and Mr. R. Smillie (members of the Royal Commission on Mines); Mr. R. A. S. Redmayne, Major Cooper-Key, Captain Desborough, and Mr. S. Harris (of the Home Office); M. Remeux (President of the French Institute of Mining Engineers); MM. Taffanel and Ringuet (Liévin Experiments Station); Dr. J. S. Holmes (United States Geological Survey); and Dr. A. Beyling (Gelsenkirchen Experiments Station).

taken into account, though the details have been recorded. The explosion travels in both directions from the point of ignition, *i.e.*, with and against the normal direction of the air current.

After the firing of the igniter, a somewhat larger cloud of coal dust is ejected from the downcast (fig. 10) ; this dust has been driven out of the gallery by the concussion caused by the igniter in advance of the explosion. After this, follows the so-called "pioneering cloud" of the explosion itself. A flame then shoots out from the mouth of the gallery about 80 ft., and, spreading through this dust, forms a subsequent flame which sometimes reaches a length of 180 ft.* (fig. 11). Simultaneously a loud report is heard similar to that noted in actual colliery disasters. This report is generally heard over a radius of $3\frac{1}{2}$ miles, whilst on one occasion, when a greater length of coal dust zone was employed (Experiment No. 25), the noise and vibration were noticed at a distance over 7 miles and were mistaken for an earthquake shock.

The interval between the firing of the igniter and the rush of flame from the mouth of the gallery is usually very small, so that it is difficult, when in a shelter near the downcast end, to distinguish any interval between the report of the igniter and the roar of the explosion. Occasionally the explosion seems to hang, and several distinct "coughs" are heard, accompanied by a whistling noise (possibly caused by air being sucked into the gallery through the joints), and an interval of several seconds appears to elapse before the ignition is propagated with explosive force.

To demonstrate the force developed by the explosions, a colliery tub, weighing about $4\frac{1}{4}$ cwts., is placed 6 ft. inside the gallery. This tub, together with many props, bars, and shelves from the interior of the gallery, is thrown violently out at the downcast end by the explosion ; the tub is generally considerably broken, the body being often found 200 ft. distant, and the frame and wheels 200 ft. further (figs. 12, 13 and 14).

As soon as the ventilating current, which has been reversed by the explosion, is re-established, dense clouds of black smoke and coal dust pass through the *evasée* chimney, the issue continuing for some time (fig. 15). Unless the explosion doors have been wrecked, the interior of the gallery is clear of afterdamp and safe for inspection in a few minutes. The effects observed compare exactly with those noted by explorers after an explosion in a mine ; those visitors who have had the experience of recovering a mine after an explosion never fail to comment on the striking similarity, after noting the displaced timber, general wreckage, crusts of coke, accumulations of dust, and the smell.

In many instances the timber for a short distance on either side of the point of ignition is undisturbed, apparently showing that the explosion had not yet gathered sufficient force to do much damage, while in other cases the whole length of the gallery, from the downcast to the return, has been swept clean, even the props that have been bolted to the side of the gallery being torn away.

When any props remain standing, indications have been furnished of the manner of formation of "broad and narrow bands" of coal dust in the gallery.

* The average length of flame projected from the downcast with the standard length of coal dust zone has been 156 ft. The distance is measured by means of posts placed at equal distances apart. These posts are 20 ft. high and carry numbers made of sheet metal which can be seen from a considerable distance.

Fig. 10.—Cloud of Coal Dust projected from the Gallery by the Igniter.

Fig. 11.—The Flame of the explosion shooting out at the Downcast End and spreading through the dust outside.

Fig. 12.—Top of Tub hurled 214 ft.

Fig. 13.—Props and Shelves ejected from the Downcast End.

Fig. 14.—Tub Wheels and broken Prop hurled 365 ft.

Fig. 15.—Dense black Smoke issuing from the Evasée Chimney as soon as the ventilating current is re-established.

Fig. 17.—Valve No. 9 being blown out.

Fig. 18.—Valves Nos. 9 and 10 after the explosion.

Fig. 19.—Wooden Evasée Chimney sucked inwards after the explosion.

The narrow thick bands are found on the sides of the props facing the normal direction of the air current, and the broad thin bands on the reverse sides.

Thus, if the point of ignition of the explosion be at A (fig. 16), and the explosion travels in both directions—towards the downcast and towards the return—the narrow, thick band on the prop is found on the side facing the downcast, and the broad, thin band facing the return.

Crusts of coke are not always to be found, but in some cases they have been observed in great quantities. They are generally found adhering to that side of the prop facing the point of ignition.

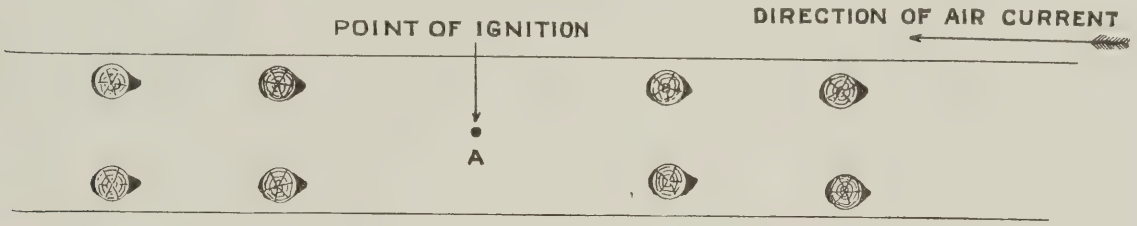



Fig. 16.

The valves at the junction and at the bends of the return have been frequently blown out : valves Nos. 9 and 10 have suffered most, and in some instances have been hurled distances of from 300 to 400 feet (figs. 17 and 18), the weight of the blown-out portions being from 4 to 6 cwts. In a few cases the doors have resisted the pressure inside the gallery, but have been so weakened that the partial vacuum, caused by the cooling of the gases after the explosion, has drawn them inwards. The fan, which had been specially selected as offering a very low frictional surface to the passage of air, has so far escaped injury, but the wooden *evasée* chimney has on one occasion been drawn inwards by the aftersuck (fig. 19).

The length of the flame inside the gallery is determined by the examination of tufts of cotton wool and guncotton,* which are fixed every few feet along the sides and are also suspended by wires in the centre. When these tufts are submitted to microscopical examination it is an easy matter to discover the most minute traces of singeing.

The meteorological conditions prevailing at the time of each experiment have been recorded, special attention being paid to the degree of saturation of the atmosphere. It is hoped that records of this character will ultimately yield valuable information.

In order to obtain permanent records of the fact that explosions have occurred, photographs have, as a general rule, been taken of the flame as it issues from the downcast end, and of the wreckage produced. In addition, the development of the flame outside the gallery has been studied by means of records obtained by the "Kinora," a form of cinematograph, which, besides providing a suitable means of reproducing the effects of the explosions for the benefit of those unable to actually witness them, afford valuable information regarding the exact sequence of events which are too rapid to be taken in by direct observation alone.†

* The use of both guncotton and cotton wool together give much better results than either of them singly, for whilst cotton wool is hardly sensitive enough to flame, guncotton may sometimes be consumed by heat without flame being present.

† Visitors will remember that they were able, by means of the "Kinora," to obtain a general impression of the manner in which the experiments are carried out—from the grinding of the dust to the projection of the flame of the explosion from the gallery. It is hoped that in the future, when the Experimental Gallery no longer exists, the "Kinora" records may prove of great educational value.

From such accounts of the British Coal Dust Experiments as have appeared in the technical Press, attempts have been made by some to institute a relationship between the length of flame projected from the downcast end, and the length of coal dust zone from which the flame arises. There is no reason why such a relationship should exist even if it were possible to make sure that the lengths of flame recorded were solely of the flame of the explosion, and not, as would appear to be the case, of the subsequent combustion of the cloud of dust which is always projected from the gallery in advance of the flame. The true flame of the explosion would appear to be about 60 or 80 feet long, such as has been noticed in an experiment made at night as a bright flash in the middle of the dense cloud of unburnt dust, while this cloud subsequently burst into a flame which spread throughout its entire bulk.

The series of Kinora pictures reproduced on Plate V. shows very clearly the manner in which the flame outside the gallery is developed from the moment of the appearance of the "pioneering cloud." In the first photograph the downcast end can be seen on the extreme right, while the ten following pictures show the cloud of dust that is driven in advance of the flame. The true flame of the explosion first makes its appearance in Nos. 11 and 12,* and increases in length until No. 15, after which it is apparent that any increase in volume and length is due to the burning of the cloud of dust that first issued.

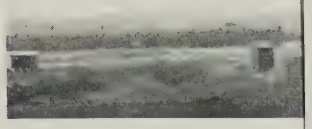
The interval between each exposure was about $\frac{1}{22}$ second, so that the total length of time that the true flame of the explosion lasted was only about $\frac{1}{5}$ second, while the subsequent combustion of the dust continued for about one second longer.

Many similar records have been obtained, all of which show the same characteristics.

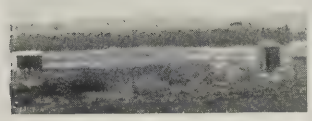
The records of seven demonstrations are reproduced in detail in the following pages.

* In all these and similar photographs of coal dust explosions, flame appears as a white patch in the middle of the black cloud of coal dust.

(1)



(2)

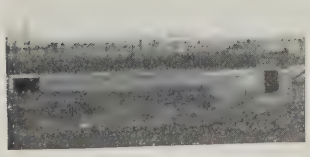


(3)

(4)

(5)

(6)



(7)

To face page 22.

# PLATE V.

SERIES OF KINORA PICTURES OF EXPLOSION.

Previous to the experiments described in the following pages, numerous attempts had been made in the summer of 1907 to obtain an explosion in a short gallery only 78 ft. long, open at both ends.

The coal dust, which was laid on the floor, was brought into suspension by a jet of compressed air, and as soon as a fairly dense cloud had been obtained, a charge of blasting powder was fired from a cannon pointing against the air current, placed at a distance of 10 ft. from the end of the tube.

In nearly every case the dust was ignited, and a large volume of flame projected from the end farthest from the cannon.

The two photographs, figs. 20 and 21, show the appearance of the flame as it issued from the end of the tube. In fig. 20 the photograph was taken facing the end of the tube, the rim of which can be seen through the cloud ; the white, or light-coloured, patches are flame.

It did not appear, however, that the inflammation was accompanied by any explosive force : therefore, when the Experimental Gallery was ready for use, it was decided that the first experiments should be made with about double the length of tubes employed in the preliminary trials ; the object being to reproduce, if possible, the destructive effects observable after an explosion in a coal mine.

FIG. 20.

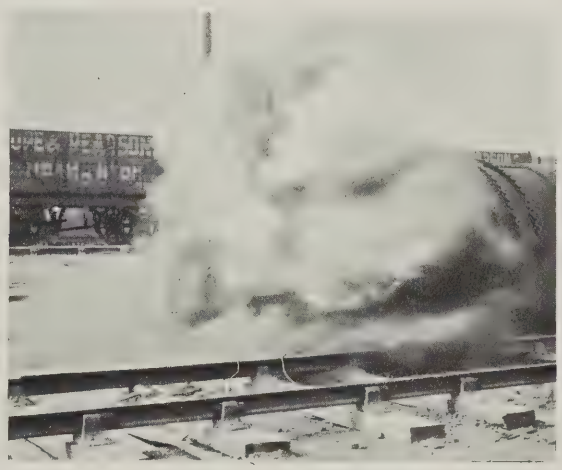


FIG. 21.

Figs. 20 and 21.—The inflammation of a cloud of coal dust in a short gallery.

It may here be remarked that explosive force was not obtained until a length of over 150 ft. of coal dust was employed. Shorter lengths gave rise to phenomena which could only be regarded as those of *inflammation*. This statement has reference only to dust from Altofts Silkstone coal ; the distance that the inflammation has to travel before explosive effects are produced will no doubt vary for dusts from different samples of coal.

## EXPERIMENT No. 1.—MAY 12th, 1908.

The records show that the flame travelled for a distance of 166 ft. from the point of ignition, but that the dynamic effects were not very great ; in fact, it appeared possible that the damage done to the explosion doors at the junction (*see* diagram) might have been largely due to the concussion arising from the firing of the 40 oz. of blasting-powder used to ignite the coal dust.

To test this, Experiment No. 2 was made on May 13th, 1908, in which the conditions were the same as in Experiment No. 1, with the exception that the

# EXPERIMENT No. 1.

MAY 12TH, 1908.

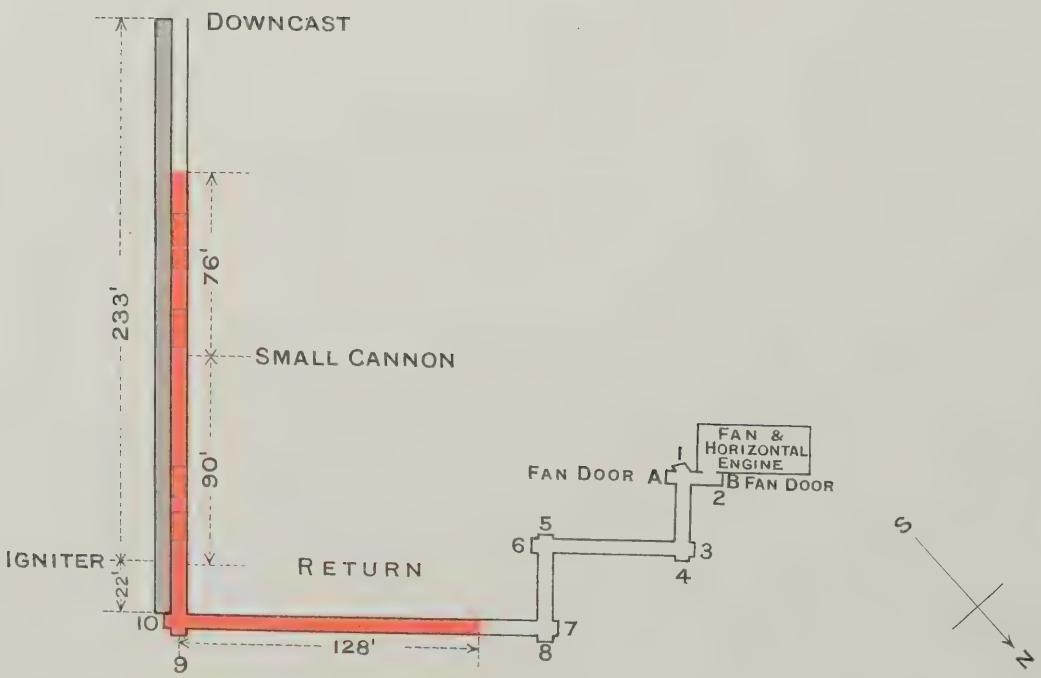
| | |
|---|---|
| LENGTH OF INTAKE ... ... ... | 255 ft. |
| SECTIONAL AREA OF INTAKE ... | 41 sq. ft. |
| LENGTH OF RETURN... ... ... | 295 ft. |
| SECTIONAL AREA OF RETURN ... | 28 sq. ft. |
| COAL DUST ZONE, 255 FT., THUS ... | |
| FLAME ... ... ... ... ... | |

## PLAN.

SCALE : $\frac{1}{960}$ or 80 ft. equals One Inch.

## METEOROLOGICAL CONDITIONS.

| | |
|---|---|
| Barometer ... .. ... ... | 29·80 in. |
| Thermometer, External ... ... | 53° Fahr. |
| Humidity, External ... ... ... | 80 % |
| General State of Weather ... ... (at time of Experiment) | Fine, 11·30 a.m. |




*NOTE.—Relief valves shown by numbers* **1, 2, 3,** *etc.*

coal dust was omitted. The results confirmed the suspicion that the cannon itself was capable of doing considerable damage, as the fan doors, A and B, were blown out, valves 3, 4, 5, 6, 7, and 8 were all sprung, and valves 9 and 10 blown out and shattered.

Subsequent experiments were therefore made with the point of ignition 96 ft. from the junction, at which distance the effects of the cannon-shot itself on the relief valves were negligible.

---

## EXPERIMENT No. 1.—May 12th, 1908.

### Main Object of Experiment.

To obtain explosive force by the ignition of coal dust without the presence of inflammable gas.

### Conditions of Experiment.

Position of igniter, 233 ft. from downcast.
Quantity of air, 43,000 cubic feet per minute.
Velocity of air, 1,048 ft. per minute.
Quantity of dust, 0·75 lb. per linear foot = 0·29 oz. per cubic foot.
Large cannon, charge 40 oz.; clay stemming 8 in.
Small cannon, charge 4 oz.; clay stemming 3 in.
Number of sets of timber in intake, 17; placed 9 ft. apart, starting from downcast end.

### Coal Used.

Seam, Silkstone; depth below surface, 960 ft.; dust collected from the screens.
Colliery, Pope and Pearson Limited, Altofts.

### Result.

A large volume of flame at the return end of the intake.
Five safety valves shattered ($\frac{3}{4}$ in. board), viz., 6, 7, 8, 9 and 10.
Valves Nos. 3, 4 and 5 badly sprung.
Fan doors A and B slightly damaged and blown open.
Evidence of flame in the intake 166 ft. from igniter.
Evidence of flame in the return 150 ft. from igniter.
Sets of timber were blown down at distances of 143, 185, 224 and 233 feet from the point of ignition.
Valves 9 and 10 blown out a distance of 63 and 102 feet.

## EXPERIMENT No. 1.

Fig. 22.—Showing Dust issuing at Valve No. 9 during the Explosion.

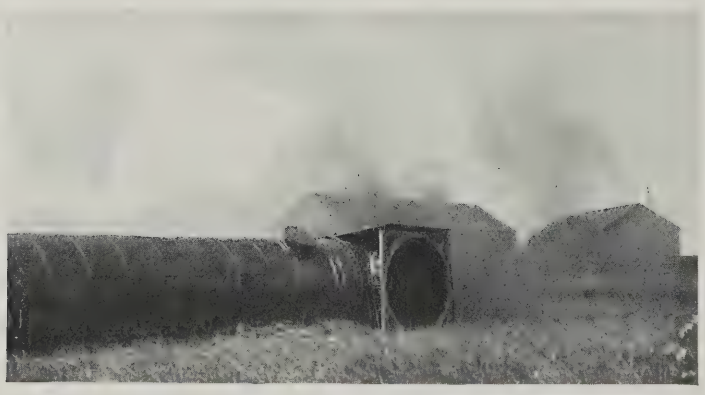


Fig. 23.—Showing Valve No. 8 blown open during the Explosion. The Door has been forced right over and is seen resting in a horizontal position.

The necessity for having the cannon placed at a distance of 96 ft. from the relief valves, which has been mentioned with reference to Experiment No. 1, made the length of the gallery insufficient to allow of more than 160 ft. of coal dust being placed in front of the point of ignition, and although it was found that this length was capable of producing marked explosive force, it was deemed desirable to increase the length of the gallery, and to experiment with greater lengths of coal dust, before undertaking to demonstrate the force of such explosions.

A relative idea of the force developed was given by the distance that an ordinary colliery tub (weighing about $4\frac{1}{4}$ cwts.), placed in the mouth of the gallery, was hurled by the explosion ; and by the number of sets of timber (placed 6 ft. apart between the point of ignition and the downcast) that had been displaced.

This is shown in the accompanying table :—

| Experiment No. | Date. | Length of coal dust (in front of point of ignition). | Length of flame beyond downcast. | Tub thrown. | Sets of timber displaced. |
|---|---|---|---|---|---|
| | 1908. | Feet. | Feet. | Feet. | |
| 6 | May 16 | 159 | 84 | 58 | 14 |
| 7 | May 18 | 159 | 71 | 24 | 9 |
| 8 | May 19 | 159 | 84 | 28 | 7 |
| 9 | May 23 | 245 | 95 | 88 | 30 |
| 10 | May 26 | 272 | 180 | 307 | 30 |
| 11 | May 30 | 272 | 120 | 268 | 31 |

## EXPERIMENT No. 12.—May 30th, 1908.

This demonstration of the explosive nature of coal dust when raised as a cloud in air was in every way convincing. A force was developed of sufficient magnitude to hurl a tub (weighing $4\frac{1}{4}$ cwts.) 314 ft., and to displace all the sets of timber along the intake.

Furthermore, the explosion appears to have travelled with almost equal force in both directions from the point of ignition, for Explosion Door No. 9, weighing $4\frac{3}{4}$ cwts., was thrown 340 ft.

The occurrence of "after-suck," or partial vacuum, after the explosion was noticed.

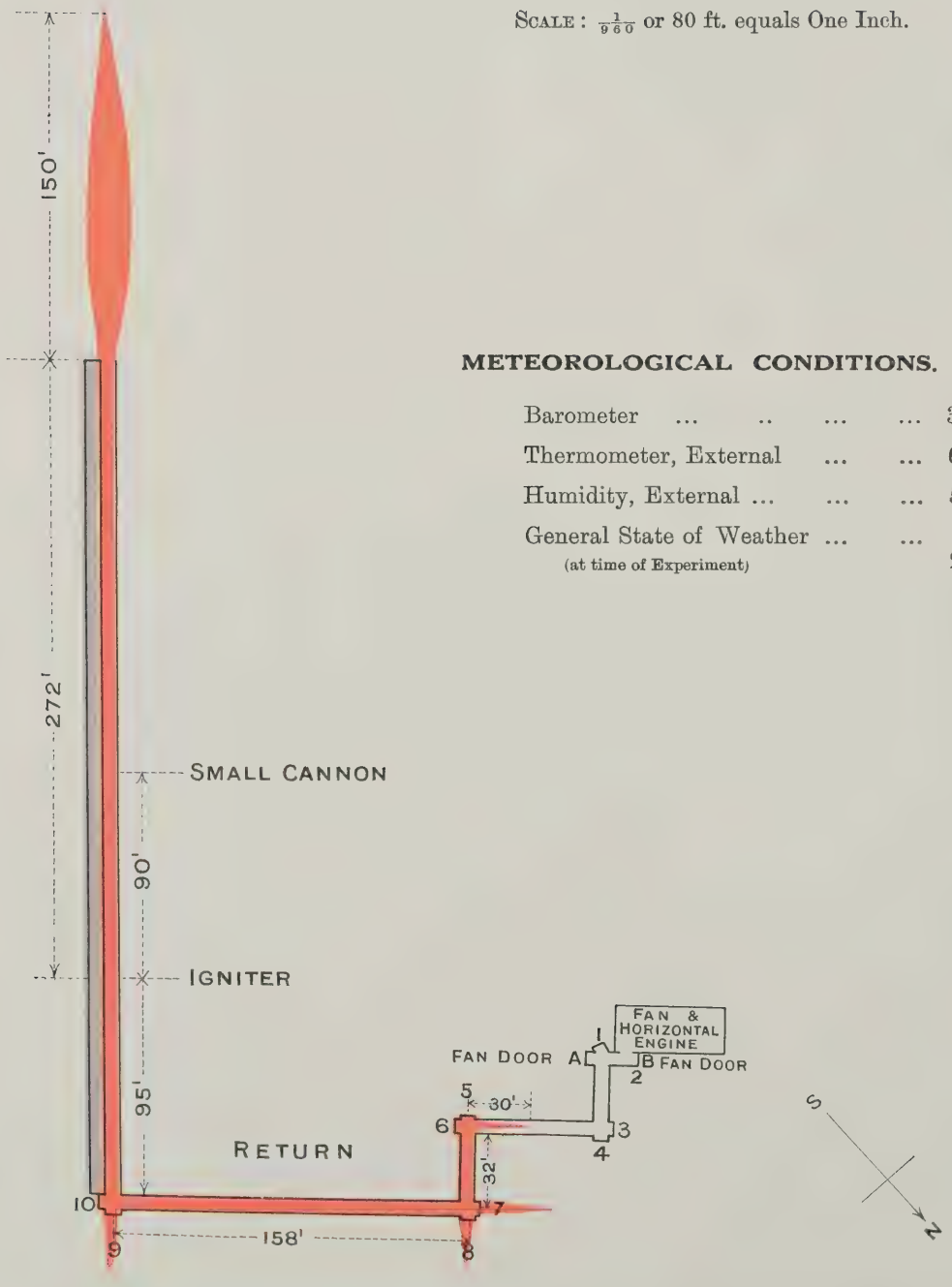
# EXPERIMENT No. 12.

MAY 30TH, 1908.

| | |
|---|---|
| LENGTH OF INTAKE ... ... ... | 367 ft. |
| SECTIONAL AREA OF INTAKE ... | 41 sq. ft. |
| LENGTH OF RETURN... ... ... | 295 ft. |
| SECTIONAL AREA OF RETURN ... | 28 sq. ft. |
| COAL DUST ZONE, 367 FT., THUS ... | |
| FLAME ... ... ... ... ... | |

## PLAN.

SCALE: $\frac{1}{960}$ or 80 ft. equals One Inch.




## METEOROLOGICAL CONDITIONS.

| | |
|---|---|
| Barometer ... .. ... ... | 30·10 in. |
| Thermometer, External ... ... | 69° Fahr. |
| Humidity, External ... ... ... | 56 % |
| General State of Weather ... ... (at time of Experiment) | Sunny, 2·50 p.m. |

***NOTE.—Relief valves shown by numbers 1, 2, 3, etc.***

## EXPERIMENT No. 12.—May 30th, 1908.

### Main Object of Experiment.

To demonstrate the explosive nature of coal dust.

### Conditions of Experiment.

Position of igniter, 272 ft. from downcast.
Quantity of air, 41,000 cubic feet per minute.
Velocity of air, 1,000 ft. per minute.
Quantity of dust, 1 lb. per linear foot = 0·39 oz. per cubic foot.
Large cannon, charge 40 oz. ; clay stemming, 8 in.
Small cannon, charge 4 oz. ; clay stemming, 3 in.
Number of sets of timber in intake, 31.

### Coal Used.

Seam, Silkstone ; collected from screens.
Colliery, Pope and Pearson Limited, Altofts.

### Result.

Flame shot out 150 ft.
Tub smashed, bottom found 314 ft. and sides 240 ft. away.
All sets of timber down, one prop sent 420 ft. away.
Valve No. 9 blown out 340 ft., the part sent out weighing $4\frac{3}{4}$ cwts.

## EXPERIMENT No. 12.

Fig. 24.—General view of explosion, showing dust and flame issuing from Downcast End. The passage of the blast along the gallery can be seen by the jets of dust escaping at the joints of the boiler-shells.

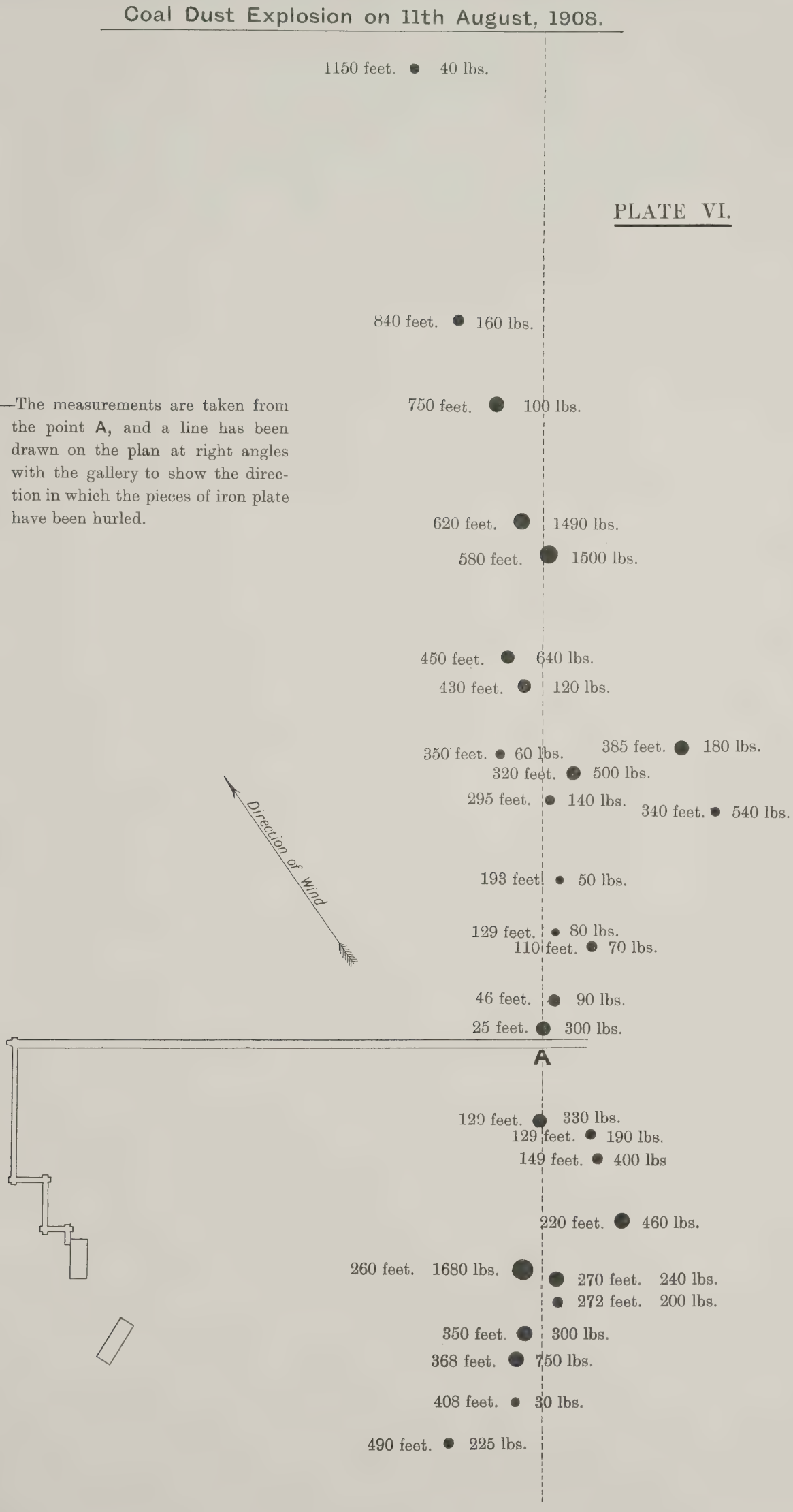
Fig. 25.—Valve No. 8 being blown out by the explosion; No. 7 blown open.

Fig. 26.—Fan-door (B), sucked inwards after the explosion.

# PLAN showing Position and Weight of Iron Plates found after the Coal Dust Explosion on 11th August, 1908.

PLATE VI.

NOTE.—The measurements are taken from the point **A**, and a line has been drawn on the plan at right angles with the gallery to show the direction in which the pieces of iron plate have been hurled.



During the months of June and July 1908, several demonstrations of coal dust explosions were made, using a length of coal dust, in front of the point of ignition, of 277 ft., namely :—

| Experiment No. | Date. |
|---|---|
| 16 | June 25th |
| 17 | June 29th |
| 18 | July 3rd |
| 21 | July 17th |

The results were, in general, similar in character to those described in Experiment No. 12, the length of flame and the force developed being of the same magnitude.

An additional length of gallery being now available, it was decided to see whether a further increase in the force developed would be observed with a still greater length of coal dust.

---

## EXPERIMENT No. 25.—August 11th, 1908.

In Experiment No. 25, therefore, 360 ft. of coal dust was placed in front of the point of ignition. The result was very alarming, and brought home in a forcible manner the power of destruction arising from an explosion of coal dust in the complete absence of inflammable gas.

Three boiler shells at the downcast end were completely wrecked, and pieces (varying in weight from 30 lb. to 1,500 lb.) were scattered over the adjacent fields (Plate VI.)

It was calculated afterwards that some pieces of the boiler shells had risen to a height of about 500 ft.*

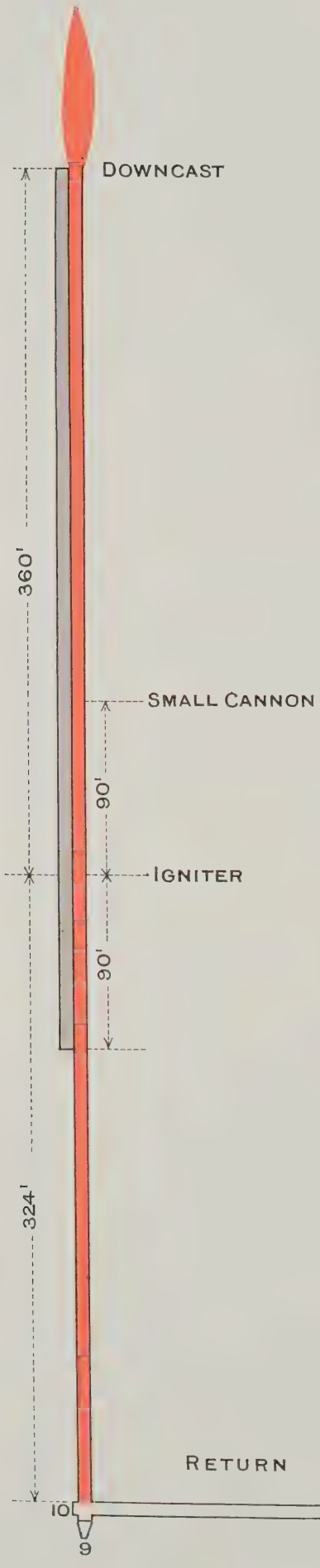
The photographs accompanying this record will give some idea of the force developed.

In trying to make an estimate of the actual pressure that must have been developed in order to cause such destruction, it must be recorded that the three boilers that were wrecked were of considerable age, and though possibly built to stand about 160 lb. *static* pressure, would not necessarily be able to resist a pressure of 100 lb. suddenly applied. Later experiments, indeed, show that it is unlikely that a pressure of more than about 120 lb. per square inch had been developed in this case.

* Such a calculation was possible from the evidence of one of the colliery officials, who, though unable to see the actual explosion, observed, from his office, the plates flying in the air above the roof of the colliery house. The angle between the man's eye and the roof of the building above which he saw the flying boiler plate gave the perpendicular height of the latter, above the place where it dropped in a cornfield, as 502 ft.

# EXPERIMENT No. 25. AUGUST 11TH, 1908.

| | |
|---|---|
| LENGTH OF INTAKE ... ... ... | 684 ft. |
| SECTIONAL AREA OF INTAKE ... | 41 sq. ft. |
| LENGTH OF RETURN... ... ... | 295 ft. |
| SECTIONAL AREA OF RETURN ... | 28 sq. ft. |
| COAL DUST ZONE, 450 FT., THUS... | |
| FLAME ... ... ... ... ... | |




## PLAN.

SCALE: $\frac{1}{960}$ or 80 ft. equals One Inch.

## METEOROLOGICAL CONDITIONS.

| | |
|---|---|
| Barometer ... .. ... ... | 29·90 in. |
| Thermometer, External ... ... | 59° Fahr. |
| ,, Internal ... ... | 60° ,, |
| Humidity, External ... ... ... | 66 % |
| ,, Internal ... ... ... | 62 % |
| Direction of Wind ... ... ... | West. |
| General State of Weather ... ... (at time of Experiment) | Fine, 3·20 p.m. |

***NOTE.—Relief valves shown by numbers 1, 2, 3, etc.***

## EXPERIMENT No. 25.—August 11th, 1908.

### Main Object of Experiment.

To see whether increased length of coal dust would develop greater explosive force.

### Conditions of Experiment.

Position of igniter, 360 ft. from downcast.

Quantity of air, 53,000 cubic feet per minute.

Velocity of air, 1,292 ft. per minute.

Quantity of dust, 1 lb. per linear foot = 0·39 oz. per cubic foot.

Large cannon, charge 24 oz. ; clay stemming, 8 in.

Small cannon, charge 4 oz. ; clay stemming, 4 in.

Number of sets of timber in intake, 86.

### Coal Used.

Seam, Silkstone seam ; pulverised nut coal.

Colliery, Pope and Pearson Limited, Altofts.

### Result.

Very violent explosion.

Flame shot out a great length from downcast end.

The three boiler shells forming the end of the intake completely wrecked ; pieces blown into the air and radially to a distance of 1,150 ft.

Valve No. 9 blown out.

Only one prop left standing at a point 66 ft. behind point of ignition.

Glass port-hole, 9 ft. behind point of ignition, blown out.

## EXPERIMENT No. 25.

FIG. 27.

FIG. 28.

FIG. 29.

Figs. 27, 28, and 29.—Damage done to the Downcast End of the Gallery.

## EXPERIMENT No. 25.

Fig. 30.—A cast-iron seating-block driven by the explosion through the side of a wagon standing in a siding 272 feet away. Also damage to siding caused by one of the large pieces of boiler-plate.

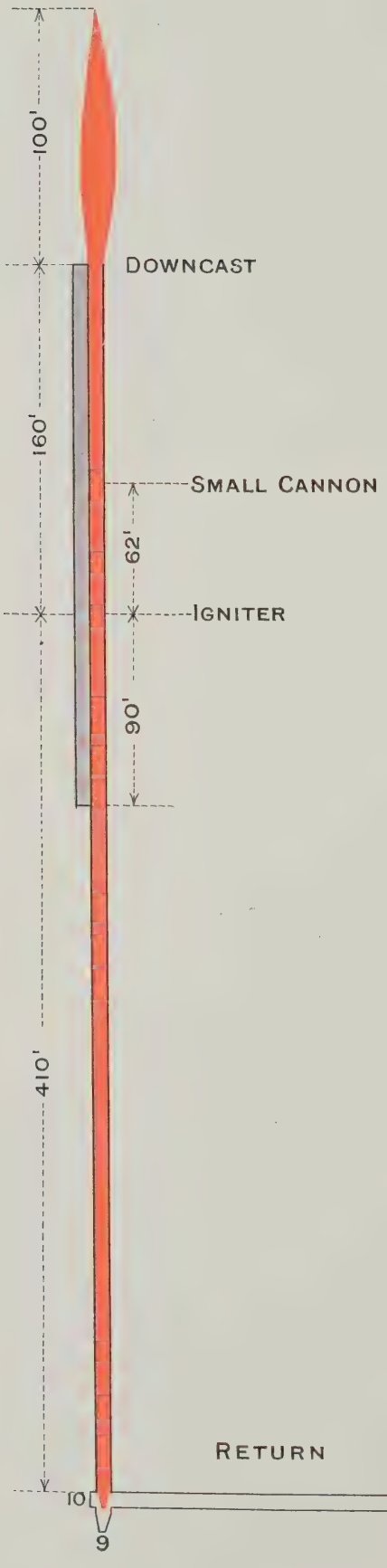
Fig. 31. Explosion Doors Nos. 9 and 10 after the explosion.

## EXPERIMENT No. 26.—August 14th, 1908.

A demonstration of an explosion, using 160 feet of coal dust in front of the point of ignition, made for the benefit of a number of French mining engineers, including the Director of the Liévin Experiments Station.

# EXPERIMENT No. 26. AUGUST 14TH, 1908.

| | |
|---|---|
| LENGTH OF INTAKE ... ... ... | 570 ft. |
| SECTIONAL AREA OF INTAKE ... | 41 sq. ft. |
| LENGTH OF RETURN... ... ... | 295 ft. |
| SECTIONAL AREA OF RETURN ... | 28 sq. ft. |
| COAL DUST ZONE, 250 FT., THUS... | |
| FLAME ... ... ... ... ... | |




## PLAN.

SCALE : $\frac{1}{960}$ or 80 ft. equals One Inch.

## METEOROLOGICAL CONDITIONS.

| | |
|---|---|
| Barometer ... .. ... ... | 29·90 in. |
| Thermometer, External ... ... | 58° Fahr. |
| ,, Internal ... ... | 59° ,, |
| Humidity, External ... ... ... | 76 % |
| ,, Internal ... ... ... | 82 % |
| Direction of Wind ... ... ... | North-West. |
| General State of Weather ... ... (at time of Experiment) | Cloudy, 11·15 a.m. |

***NOTE.—Relief valves shown by numbers 1, 2, 3, etc.***

## EXPERIMENT No. 26.—August 14th, 1908.

### Main Object of Experiment.

Demonstration of the explosive nature of coal dust, to French mining engineers.

### Conditions of Experiment.

Position of igniter, 160 ft. from downcast.
Quantity of air, 55,000 cubic ft. per minute.
Velocity of air, 1,340 ft. per minute.
Quantity of dust, 1 lb. per linear foot = 0·39 oz. per cubic foot.
Large cannon, charge 40 oz. ; clay stemming, 8 in.
Small cannon, charge 4 oz. ; clay stemming, 4 in.
Number of sets of timber in intake, 36.

### Coal Used.

Seam, Silkstone Seam ; pulverised nut coal.
Colliery, Pope and Pearson Limited, Altofts.

### Result.

Large volume of flame (about 100 ft. long) shot out at downcast end.
Ten props and six bank bars were blown out and scattered over the ground.
The tub bottom was blown 135 ft., and the sides 214 ft.
One set of timber remained standing 5 ft. in front of igniter.
One half-set remained standing 51 ft. behind igniter.

## EXPERIMENT No. 26.

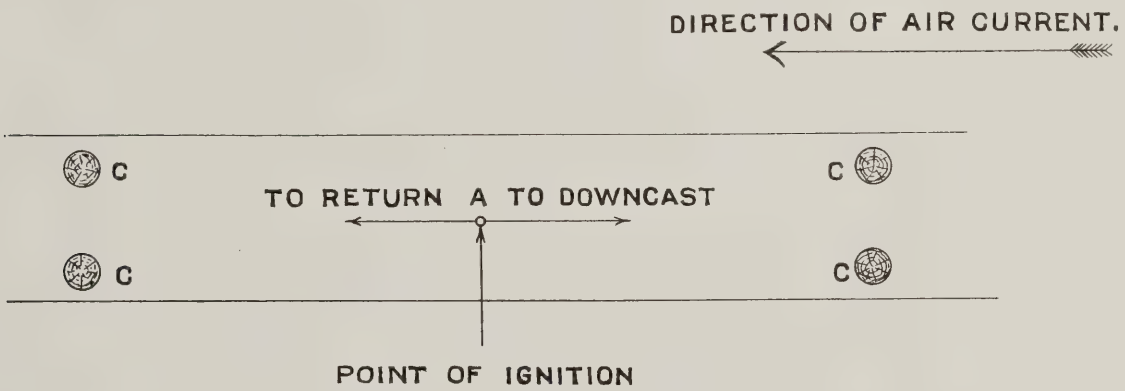
Fig. 32.—Flame issuing from the Downcast.

Fig. 33.—Showing distance that the bottom and wheels of the tub were thrown.

## EXPERIMENT No. 28.—September 25th, 1908.

In this, as in some of the previous experiments, coking was observed on such props and timbers as had remained standing after the explosion. The position that this coking occupied relative to the point of ignition is of importance in connection with the attempts made by explorers after a colliery disaster to locate the origin of the explosion.

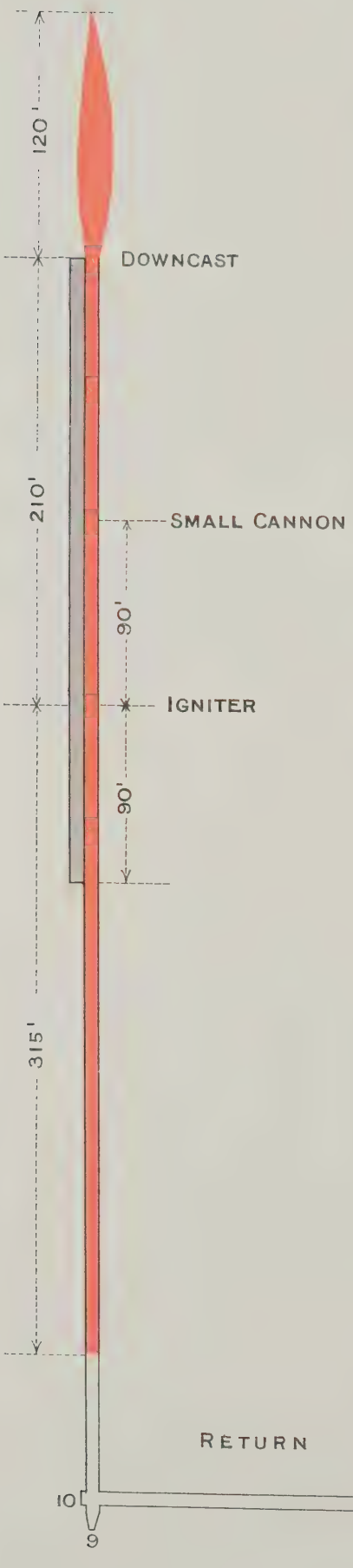
This subject has already been mentioned in the general description of the results, together with the question of the position of the broad and narrow bands of coal dust. The facts recorded in this particular experiment were as follow :—




The point of ignition being at A, and the explosion travelling in each direction from it, the crusts of coke were in every case found on the sides of the props facing the explosive blast, *i.e.*, at *c*, *c*, *c*, *c* in the above diagram.

# EXPERIMENT No. 28. SEPTEMBER 25TH, 1908.

| | |
|---|---|
| LENGTH OF INTAKE ... ... ... | 600 ft. |
| SECTIONAL AREA OF INTAKE ... | 41 sq. ft. |
| LENGTH OF RETURN... ... ... | 295 ft. |
| SECTIONAL AREA OF RETURN ... | 28 sq. ft. |
| COAL DUST ZONE, 300 FT., THUS ... | |
| FLAME ... ... ... ... ... | |




## PLAN.

SCALE : $\frac{1}{960}$ or 80 ft. equals One Inch.

## METEOROLOGICAL CONDITIONS.

| | |
|---|---|
| Barometer ... .. ... ... | 30·00 in. |
| Thermometer, External ... ... | 60° Fahr. |
| ,, Internal ... ... | 65° ,, |
| Humidity, Internal ... ... ... | 83 % |
| General State of Weather ... ... (at time of Experiment) | Fine, 1·30 p.m. |

***NOTE.—Relief valves shown by numbers 1, 2, 3, etc.***

## EXPERIMENT No. 28.—September 25th, 1908.

### Main Object of Experiment.

Demonstration of coal dust explosion to members of the Royal Commission on Mines.

### Conditions of Experiment.

Position of igniter, 210 ft. from downcast.

Quantity of air, 53,000 cubic feet per minute.

Velocity of air, 1,290 ft. per minute.

Quantity of dust, 1 lb. per linear foot = 0·39 oz. per cubic foot.

Large cannon, charge 24 oz. ; clay stemming, 8 in.

Small cannon, charge 4 oz. ; clay stemming 4 in.

Number of sets of timber in intake, 69.

### Coal Used.

Seam, Silkstone ; pulverised nut coal.

Colliery, Pope and Pearson Limited, Altofts.

### Result.

Large volume of flame shot out at downcast end to a distance of 120 ft.

Tub sent 150 ft.

Evidence of flame inside the gallery for 315 ft. behind igniter.

Twenty-nine sets of timber blown down.

There was a layer of coked dust (over $\frac{1}{2}$ in. thick) on the return side of the props that remained standing in front of the igniter, and a similar layer on the downcast side of those that remained standing behind the igniter.

## EXPERIMENT No. 28.

Fig. 34.—Flame issuing from Downcast End. Near View.

NOTE.—The tubes shown on the right of the photograph did not form part of the gallery at the time of this experiment.

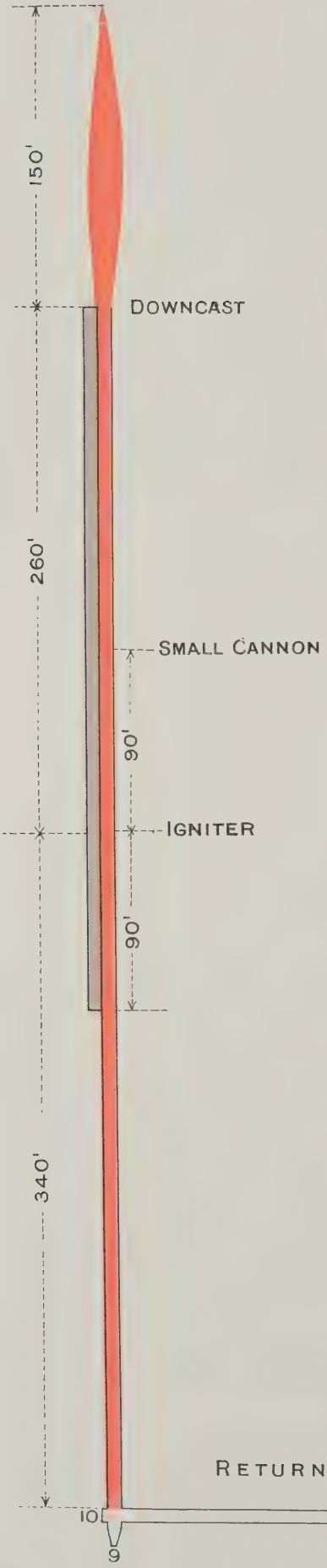
Fig. 35.—General view of Explosion.

## EXPERIMENT No. 35.—October 28, 1908.

Bourdon pressure gauges had been placed, 50 ft. apart, along the whole length of the gallery. Although it was recognised that such gauges could not be expected to give accurate measurements of such suddenly applied pressures as occur during the explosion, it was hoped that some idea of the relative changes of pressure at different points might be obtained. The results cannot, however, be relied upon, and it is thought best not to attempt any calculations from them.

# EXPERIMENT No. 35. OCTOBER 28TH, 1908.

| | |
|---|---|
| LENGTH OF INTAKE ... ... ... | 600 ft. |
| SECTIONAL AREA OF INTAKE ... | 41 sq. ft. |
| LENGTH OF RETURN... ... ... | 295 ft. |
| SECTIONAL AREA OF RETURN ... | 28 sq. ft. |
| COAL DUST ZONE, 350 FT., THUS... | |
| FLAME ... ... ... ... ... | |




## PLAN.

SCALE : $\frac{1}{960}$ or 80 ft. equals One Inch.

## METEOROLOGICAL CONDITIONS.

| | |
|---|---|
| Barometer ... .. ... ... | 30·00 in. |
| Thermometer, External ... ... | 51° Fahr. |
| ,, Internal ... ... | 60° ,, |
| Humidity, External ... ... ... | 80 % |
| ,, Internal ... ... ... | 71 % |
| Direction of Wind ... ... ... | South-West. |
| General State of Weather ... ... (at time of Experiment) | Fine, 1·5 p.m. |

***NOTE.—Relief valves shown by numbers 1, 2, 3, etc.***

## EXPERIMENT No. 35.—October 28th, 1908.

### Main Object of Experiment.

Demonstration to mining engineers of explosion due to coal dust without the presence of inflammable gas.

### Conditions of Experiment.

Position of igniter, 260 ft. from downcast.

Quantity of air, 60,000 cubic feet per minute.

Velocity of air, 1,460 ft. per minute.

Quantity of dust, 1 lb. per linear foot = 0·39 oz. per cubic foot.

Large cannon, charge 24 oz. ; clay stemming, 8 in.

Small cannon, charge 4 oz. ; clay stemming, 4 in.

Number of sets of timber in intake, 66, 9 ft. apart ; at every 100 ft. the props were bolted to the gallery.

### Coal Used.

Seam, Silkstone ; pulverised nut coal.

Colliery, Pope and Pearson Limited, Altofts.

### Result.

Violent explosion.

Flame shot out at downcast end about 150 ft.

Tub wrecked, wheels found 490 ft., sides 300 ft., away.

No unclamped props remained standing. Of the clamped props, one only remained standing in front of the point of ignition, at a distance of 254 ft. ; behind the point of ignition three remained at 44, 143, and 242 ft. respectively.

## EXPERIMENT No. 35.

Fig. 36.—Flame of explosion issuing from Downcast End. (Marked 35).

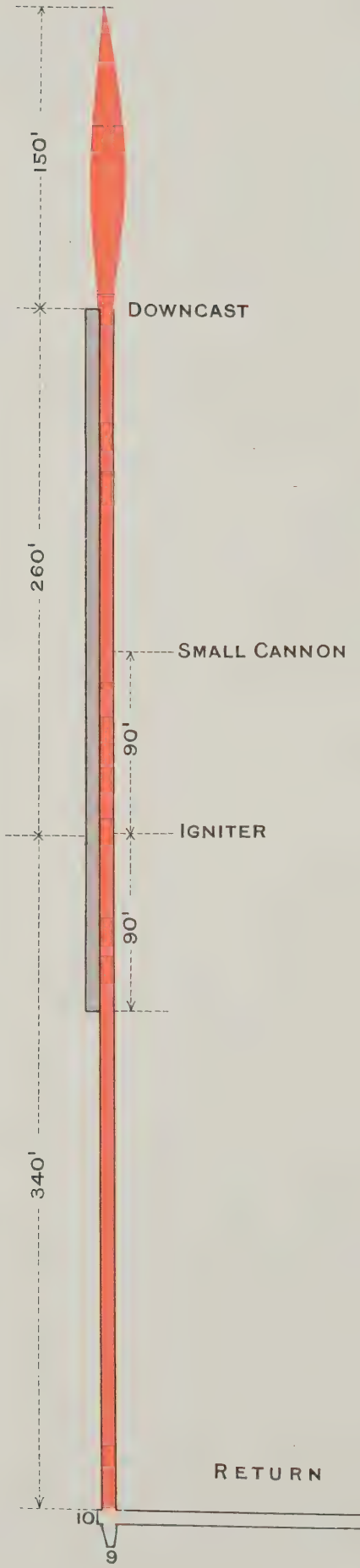
Fig. 37.—Valve No. 8 being blown open by the force of the explosion.

EXPERIMENT No. 36.—November 4th, 1908.

A demonstration of a coal dust explosion to mining engineers from South Wales.

# EXPERIMENT No. 36. NOVEMBER 4TH, 1908.

| | |
|---|---|
| LENGTH OF INTAKE ... ... ... | 600 ft. |
| SECTIONAL AREA OF INTAKE ... | 41 sq. ft. |
| LENGTH OF RETURN... ... ... | 295 ft. |
| SECTIONAL AREA OF RETURN ... | 28 sq. ft. |
| COAL DUST ZONE, 350 FT., THUS... | |
| FLAME ... ... ... ... ... | |




## PLAN.

SCALE: $\frac{1}{960}$ or 80 ft. equals One Inch.

## METEOROLOGICAL CONDITIONS.

| | |
|---|---|
| Barometer ... .. ... ... | 30·12 in. |
| Thermometer, External ... ... | 50° Fahr. |
| ,, Internal ... ... | 62° ,, |
| Humidity, External ... ... ... | 93 % |
| ,, Internal ... ... ... | 72 % |
| Direction of Wind ... ... ... | West. |
| General State of Weather ... ... (at time of Experiment) | Fine, 1·5 p.m. |

***NOTE.—Relief valves shown by numbers 1, 2, 3, etc.***

## EXPERIMENT No. 36.—November 4th, 1908.

### Main Object of Experiment.

Demonstration of coal dust explosion to mining engineers from South Wales.

### Conditions of Experiment.

Position of igniter, 260 ft. from downcast.

Quantity of air, 54,000 cubic feet per minute.

Velocity of air, 1,320 ft. per minute.

Quantity of dust, 1 lb. per linear foot = 0·39 oz. per cubic foot.

Large cannon, charge 24 oz. ; clay stemming 8 in.

Small cannon, charge 4 oz. ; clay stemming 4 in.

Number of sets of timber in intake, 66, 9 ft. apart ; the props at every 100 ft. were bolted to the gallery.

### Coal Used.

Seam, Silkstone ; pulverised nut coal.

Colliery, Pope and Pearson Limited, Altofts.

### Result.

Violent explosion.

Flame shot out at downcast end about 150 ft.

Evidence of flame inside the gallery for 340 ft. behind igniter

Tub wrecked, wheels found 452 ft. away.

## EXPERIMENT No. 36.

Fig. 38. Flame issuing from Downcast End.

Fig. 39.—Valves 7 and 8 being blown open by the Explosion.

Fig. 40.—Valve 7, after the Explosion, drawn inwards by suction.

After the successful experiment on May 30th, 1908 (No. 12), the Committee considered that the explosive nature of coal dust when raised as a cloud in air, and in the complete absence of firedamp, had been fully proved, and that they should therefore proceed immediately to conduct experiments to test the value of the practical remedies that had been suggested.

The remedy that appeared to the Committee to be most worthy of trial was that suggested by Mr. Garforth as the outcome of his personal observations during the recovery of the Altofts Silkstone Pit after the explosion in 1886. At that time he noticed that the explosive blast had traversed all the haulage roads containing a preponderance of coal dust, and had caused great destruction there ; but that the evidence of flame and force disappeared when the stone dust roads were reached* (*see* Plate XIII.). From this experience, which extended over several months while the workings were being recovered, he deduced that a coal dust explosion could be checked if an incombustible dust were present in sufficient quantity.

It was therefore decided to test the value of stone dust first, and to lengthen the gallery for this purpose.

The first trial of stone dust was carried out on July 18th, 1908 (Experiment No. 22), and several other trials were made during 1908. The results were such as to cause the officials of the Altofts Collieries to regard the application of stone dust as a practical undertaking, and to experiment as to the best means of applying it underground. In order to avoid needless repetition, however, the Committee consider that it is preferable to defer the description of the stone dust experiments until later in this Report ; for experiments were made during 1909, similar in character to those of 1908, in which it was possible to record the data more accurately by means of specially-designed instruments. The experiments of 1909 are therefore more suitable for detailed description than those of 1908, which depended for their value largely on personal observation.

The Committee recognised that any remedial measure which might be tried would rest on a surer foundation if the practical tests were supported by scientific investigation. They therefore decided, at a meeting held on May 30th, 1908, to appoint a chemist and physicist who should reside at the Experimental Station and devote the whole of his time to the work, the object being to investigate the chemical and physical phenomena. Dr. R. V. Wheeler, D.Sc., and late Dalton Scholar and Fellow of Manchester University, was appointed. As a former pupil of Professor H. B. Dixon, he had previously devoted particular attention to the study of combustion and gaseous reactions and had collaborated in several researches on such subjects with Dr. W. A. Bone (now Professor of Fuel and Gas Engineering at the University of Leeds), on whose recommendation the post was offered to him.

* Evidence given before the Royal Commission on Coal Dust in Mines, July 2, 1891 :—

Q. No. 3716. "What conclusion do you draw from that?"—A. "That those roads containing "coal dust were affected, those containing dirt dust or only a slight sprinkling of coal dust "were not affected. When the explosion took place at No. 3 shot the flame traversed the "West and No. 1 chain roads, but on arriving at the cross-gates where the ripping stone "smothers the coal dust it gradually ceased. . . . No damage was done in the returns, "nor did we find the slightest damage in the working places all round the pit."

Q. No. 3717. "And you attribute that to the absence of dust in those roads?"—A. "I do ; and "to the stone dust instead of the coal dust."

Q. No. 3774. "What are the particular points upon which you think further experiments are "necessary?"—A. "I think you should conduct experiments on the different kinds of coal "dust and dirt dust. I believe dirt dust will really be the means of preventing an explosion "on some roads—more so than watering."

The first few months after his appointment were spent by Dr. Wheeler in studying the published records of previous work relating to the coal dust question, and, in conjunction with Mr. Horace Darwin, F.R.S., of the Cambridge Scientific Instrument Company, in determining the design of the instruments that would be required. In this connection the demonstrations of the explosive character of coal dust that were made during the later months of 1908 were of considerable value in affording them a practical notion of the type of phenomena which it would be necessary to record, and the vibration and pressure that the instruments would have to withstand. The heartiest thanks of the Committee are due to Mr. Darwin for the great interest that he has shown in, and the personal attention he has given to the designing of the instruments.

As there were many questions concerning the effect of heat upon coal dust which would require elucidation, it was decided that a laboratory should be built and equipped specially for the purpose, at the Experimental Station. This building, a plan of which is shown in fig. 41, was completed by March 1909. Its outside dimensions are 75 ft. by 25 ft. It is supplied with electric current for lighting (100 volts) and power (200 volts), and is fitted with all the requisites of a modern chemical and physical laboratory. A photograph of the interior of the Gas Analysis Room is shown in fig. 42.

While this laboratory was being built, the chemical work was carried out in the laboratories of one of the Universities, a commencement being made as soon as the atmospheric conditions at Altofts rendered it inadvisable to continue the experiments in the gallery.

In this connection the Committee consider it advisable to draw attention to the fact that the problem of coal dust explosions is complicated by the lack of exact knowledge that exists regarding coal itself. They therefore considered it necessary to institute investigations upon the nature of coal, and the action of heat upon coal dust, simultaneously with those upon the nature of explosive combustion of coal dust and air, and they decided to give special attention to all such questions as still form the subject of controversy amongst mining engineers.

If the investigation were carried out on these lines, the Committee considered that the combination of practical trials with scientific investigations would place the whole enquiry upon a sure foundation.

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PLAN OF LABORATORY

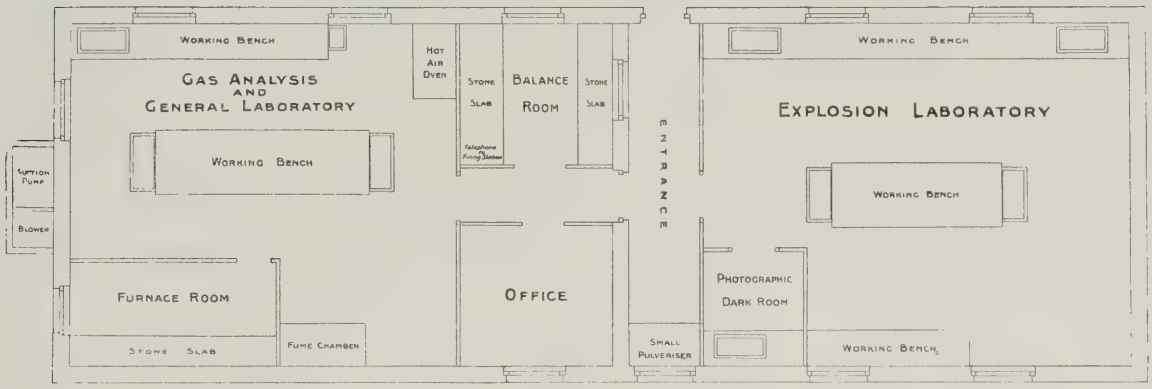


Fig. 41.—Plan of Laboratory.

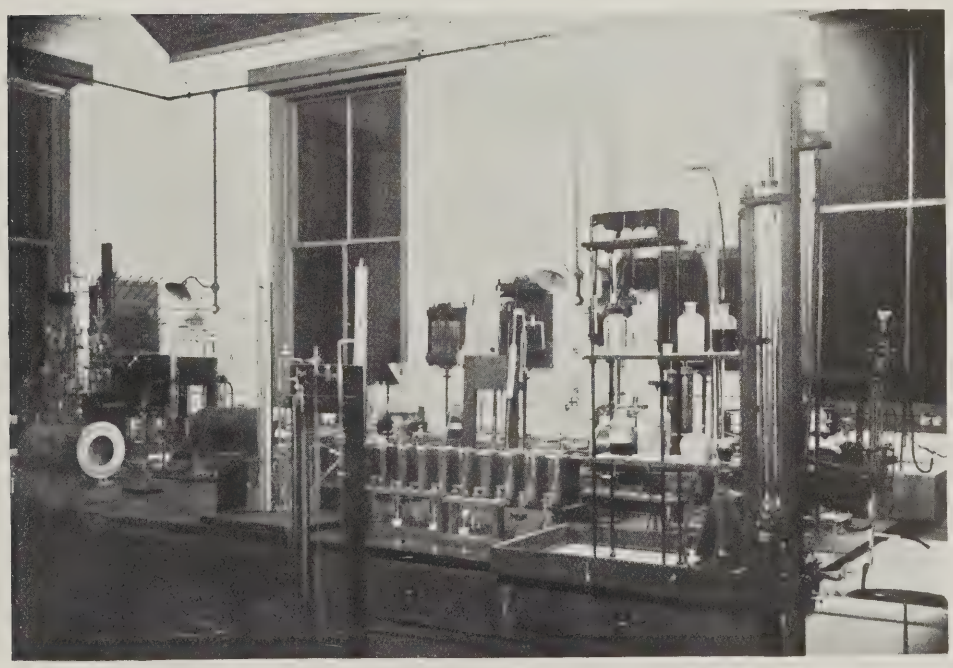

Fig. 42.—Interior of Gas Analysis Room of Laboratory.

## CHAPTER IV.

# THE CHEMICAL ANALYSIS OF COAL DUST.

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# THE CHEMICAL ANALYSIS OF COAL DUST.

It is, naturally, important that the methods adopted for determining the chemical constitution of the different kinds of coal to be tested should be capable of giving accurate and concordant results. The Committee therefore consider it necessary to give a short account of the methods of analysis that have been used.

If possible, methods of analysis which are universally recognised as standard should be employed, in order that a true comparison can be made between one coal and another and as between one worker and another. It may here be remarked that, unless the methods of analysis which have been employed are known to have been the same when comparison between two samples of coal is attempted, the deductions drawn will probably be at fault.

It was essential, therefore, that any attempt to institute a comparison between samples of coal from their chemical constitution should be based upon results obtained on the spot from analyses conducted with a strict attention to uniformity in treatment.

After testing the numerous methods that have been devised for determining the different constituents of coal, it was found that the most uniform results were given by those described below.

## PROXIMATE ANALYSIS.

### Moisture.

The most accurate method is to heat a weighed quantity of the coal at a temperature of 105 degs. Cent. in a current of dry air (or hydrogen), and, by causing the air, after passing over the coal, to pass through weighed tubes containing calcium chloride, to weigh the actual quantity of water given off.

If an attempt be made to determine the amount of moisture indirectly from the loss in weight of the coal on heating in air to a temperature of 105 degs. Cent., an error is introduced owing to the fact that many coals undergo oxidation at this temperature, and the change in weight may be partly due to change in chemical constitution. However, if care be taken that the time of heating is not too long, and if the different samples are in the same state of division, the error arising from using the shorter, indirect method is not very important.

As has been explained earlier in this Report, the coal dust used in the explosions was obtained by pulverising nut coal. In order to obtain uniform data, all analyses and tests in the laboratory have been made with the pulverised coal, a large sample (about 1 kilogramme) being collected little by little throughout the operation of pulverising. This sample is then sieved, and only that portion which passes through a 240 mesh sieve (usually about 75 per cent. of the whole) is taken for analysis.

It was interesting, therefore, to see what measure of uniformity would be obtained in the determination of moisture in dust of this degree of fineness, and also what difference, if any, would occur when a coarser dust was used—for the finer the dust the more rapidly should any oxidation take place during the determination.

Two series of determinations were therefore made, using as a standard a large sample of pulverised Altofts Silkstone nuts; this large sample was kept in an air-tight screw-top tin and employed for all the preliminary tests of methods of analysis.

The method employed was to heat 1 gramme of the dust for each determination in an open porcelain crucible of 40 mm. diameter in an electrically-heated oven for one hour at a temperature of 105 degs. Cent. After heating, the crucibles containing the samples were allowed to cool with exclusion of air in a desiccator over strong sulphuric acid and weighed covered; the loss in weight was taken as being due to the moisture having been driven off.

The results were as follow :—

| No. | Fineness. | |
|---|---|---|
| | Through 240 mesh. | Through 100 on 150. |
| | Per cent. moisture. | Per cent. moisture. |
| 1 | 3·20 | 3·10 |
| 2 | 3·26 | 3·16 |
| 3 | 3·22 | 3·03 |
| 4 | 3·24 | 3·18 |
| 5 | 3·21 | 3·13 |
| 6 | 3·22 | 3·12 |
| 7 | 3·22 | 3·12 |
| 8 | 3·21 | 3·13 |
| Mean | 3·22 | 3·12 |

It will be seen that while the two series agree very well among themselves, the finer dust gives a mean value 0·10 per cent. higher than the coarser.

### Volatile Matter.

A weighed sample of the dried dust is placed in a platinum crucible 40 mm. high and 32 mm. in diameter. The crucible is heated, with the lid on, for exactly seven minutes over a Bunsen burner, the flame of which, when burning freely, is 20 to 22 centimetres high. The crucible is supported on a triangle of thin platinum wire at such a height that the distance between the top of the burner and the bottom of the crucible is from 6 to 8 centimetres. The flame is protected from draughts by a metal hood. After being cooled in a desiccator, the crucible and residue are weighed, the loss in weight being taken as due to the driving off of the volatile constituents of the coal.

### Fixed Carbon and Ash.

The coke remaining after the volatile matter has been driven off is ignited, with free access of air, in an electric muffle furnace. Any iron pyrites present is converted almost entirely into iron oxide ($Fe_2O_3$), so that the weight of the true ash is less than the weight of the residue left, after burning off all the carbon in the coke, by five-eighths the weight of the sulphur present as pyrites. The loss in weight is taken to be "fixed carbon."

In order to be able to compare exactly the behaviour of different samples of coal on subsequent treatment, the percentages of volatile matter and fixed carbon are also calculated for ash-free dry coal—that is to say, as percentages of the pure combustible matter present.

Reference has already been made to the differences observed in the percentages of moisture as determined in two different degrees of fineness of the same dust. In the course of experiments with different methods of determining the volatile matter, fixed carbon, and ash, similar differences were observed, and it was thought at first that such discrepancies were directly due to the difference in the fineness of the sample, and that, in order to be comparable, the state of division of samples of different coal must always be the same. For example, the following series of analyses was made with the large sample of Silkstone dust already referred to :—

| Fineness of dust. | Volatile matter. | Ash. |
|---|---|---|
| | Per cent. | Per cent. |
| On 100 mesh | 39·27 | 4·59 |
| Through 100 on 150 | 36·72 | 3·86 |
| Through 150 on 200 | 36·58 | 4·71 |
| Through 200 on 240 | 35·70 | 4·25 |
| Through 240 and finer | 33·80 | 5·80 |

Such wide differences, however, led to the suspicion that there might be a variation in the actual composition of the fractions remaining on the different sieves, due to one part of the coal being more readily pulverised than another.

In order to test this, a sample of the dust which had passed through 100 mesh and remained on 150, was ground in an agate mortar until it all passed through a 240 mesh sieve ; this then gave on analysis :—

| | |
|---|---|
| Volatile matter | 36·44 per cent. |
| Ash | 4·00 „ |

Comparing this result on the one hand with the analysis of the main bulk of the dust that had passed through 100 and had remained on 150, and on the other hand with the sample obtained from the main bulk of the " through 240," we get :—

| | Volatile matter. | Ash. |
|---|---|---|
| | Per cent. | Per cent. |
| 1. Original "through 100 on 150" | 36·72 | 3·86 |
| 2. No. 1 ground to pass through 240 | 36·44 | 4·00 |
| 3. Original "through 240" | 32·30 | 5·80 |

These figures show that the wide difference in composition is actual and not due to the method of analysis giving varying results when the state of division of the sample differs.

In order to settle whether the small difference (0·28 per cent.), was caused by the difference in fineness, one lump of the Silkstone coal, nut size, was ground in an agate mortar until it all passed through a 100 mesh sieve. This dust was then divided into three portions :—

1. Through 100 on 150.
2. No. 1 ground to pass through 240.
3. Original dust through 240.

The three dusts were then analysed, and gave the following results (calculated on the ash-free dry coal):—

| | Volatile matter. |
|---|---|
| 1 | 39·20 per cent. |
| 2 | 38·90 ,, |
| 3 | 37·80 ,, |

It will thus be seen that the actual fineness of the dust is accountable for a slight difference, of about 0·30 per cent., in the volatile matter determination as conducted in a platinum crucible.

The main difference is, however, due to a real difference in composition.

Consideration of these results made it advisable, in analysing the dust used in the explosion experiments, to employ only that fraction which passes through a 240 mesh sieve ; this is the main bulk of the dust, about 75 per cent., and, moreover, it is the finer dust which enters most largely into the explosive combustion.

### Ultimate Analysis.

In addition to distinguishing between the proximate constituents (volatile matter, coke and ash), it is necessary to determine the ultimate chemical composition as expressed by the percentage of each of the elements—carbon, hydrogen, oxygen, nitrogen and sulphur—that are contained in the combustible matter.

The carbon and hydrogen are determined by the usual method of organic combustion, a small quantity of the coal being burnt in a current of dried oxygen, and the water and carbonic acid thus formed collected and weighed, the former by passing through a calcium chloride tube and the latter by absorption in caustic potash. Any sulphur dioxide that may be formed by combustion of the organic sulphur in the coal is removed by passing through a layer of lead chromate heated to redness, before the products of combustion pass through the calcium chloride tube.

Sulphur is determined by Eschka's method, the heating being conducted in an electric muffle furnace. Nitrogen is determined by a modification of Kjeldahl's method.* The oxygen is estimated by difference—that is, by subtracting the sum of the figures obtained for carbon, hydrogen, nitrogen and sulphur (all calculated as percentages of pure combustible matter present), from 100·00.

## THE VOLATILE CONSTITUENTS OF COAL.

The ordinary laboratory determination of the "volatile matter" in coal is unsatisfactory, as it only enables the total quantity by weight to be estimated without affording much information as to its *nature*. It was necessary, therefore, to devise a method of determining both the quantity and the nature of the volatile constituents which could be readily carried out, and which would be capable of giving uniform results.

The method finally fixed upon was to distil a known weight of the coal in a thin platinum retort, and to collect the gases evolved after passing through a "scrubber" to remove tar.

Two grammes of the coal to be tested, dried at 107 degs. Cent., and in the form of dust of known fineness, are intimately mixed with 3 grammes of ignited silica

* Details of these methods can be obtained from any standard work on fuel analysis.

sand. This admixture with sand is necessary to ensure uniform heating, and to prevent sudden evolution of gas with consequent projection of some of the coal on to the sides of the retort. The mixture is placed in a thin platinum boat B (fig. 43), 13 cm. long, which slides easily into the retort R, which consists of a platinum tube, 21·5 cm. long, and of 1·7 cm. internal diameter. This tube is silver soldered into a gunmetal collar with a wide flange ; a similar flange carrying a short length of gunmetal leading-tube L of 1 cm. bore can be bolted on to the retort by six small screws through holes round the circumference of the flanges. The face connected with the leading-tube has a projecting ring, midway between the centre and circumference, which can be pressed true into a corresponding sunk ring on the retort face, using a washer of asbestos and graphite. A perfect vacuum-tight connection can be made in this manner.

Before this connection is made, a tar scrubber is fitted into the mouth of the retort. This scrubber S consists of a platinum tube packed with ignited asbestos fibre and open at both ends ; it is 16·5 mm. in diameter for 8 cm. of its length, and then narrows into a tube 0·8 mm. in diameter and 5·5 cm. long. These dimensions allow of the scrubber occupying the position shown in fig. 43, the wide portion making a

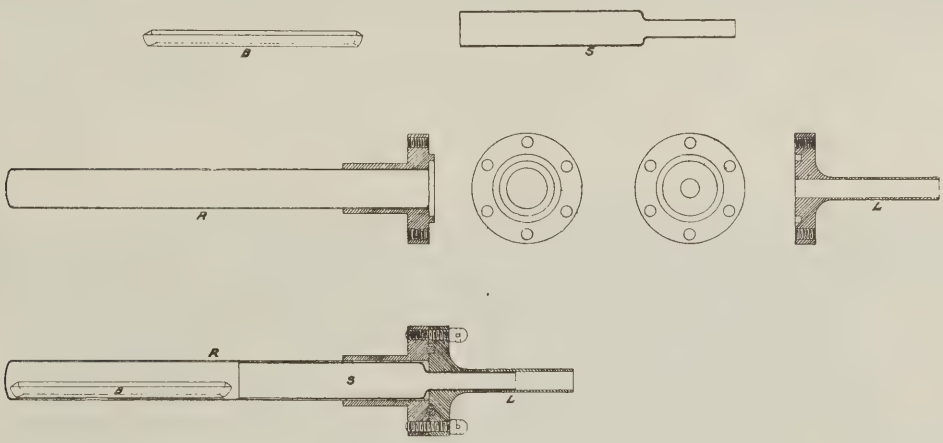


Fig. 43.—Platinum Retort and Connections for the Distillation of Coal.

good sliding fit inside the retort so as to prevent any tar vapour from escaping without passing through the asbestos.

The connection to the retort having been made, the gunmetal leading-tube is joined, by stout rubber pressure tubing, to a mercury manometer and a 2-litre gas-holder.

The retort is now exhausted of air, through the glass taps $t$, T, $t'$ (fig. 44), the tap $t$ is closed, and tap T, which is a three-way tap, turned so as to make connection with the gas-holder and the retort as soon as $t$ is opened.

The whole arrangement is mounted upon a wooden support and runs on wheels so as to allow of its being quickly pushed into the electric tube furnace which has been previously brought to the experimental temperature (900 degs. Cent.).

As soon as the pressure of the gases evolved on heating is equal to the atmospheric pressure, the tap $t$ is opened and the gas at once passes into the gas-holder and is collected. Heating is continued for a definite period, usually seventy-five minutes, and the retort then withdrawn and allowed to cool. The gases

remaining in the retort are then withdrawn by means of a Sprengel mercury pump and added to the main bulk in the gas-holder (fig. 45).

The gunmetal joint can now be disconnected, the tar-scrubber and the boat removed and weighed, and the gases analysed.

In this manner the following data are obtained :—

1. Rate of evolution of gas.
2. Volume of gas evolved.
3. Composition of this gas.
4. Quantity of tar formed.
5. Total loss in weight of the coal, *i.e.*, total volatile matter.

The whole operation, including that of analysing the gas, takes about three hours, and this method has been adopted as the standard for the British Coal Dust Experiments for the determination of the volatile constituents of different samples of coal. The method previously described is only employed for the routine analyses of the dust used in the explosion experiments to see whether it is keeping uniform in quality.

## The Electric Furnace.

In order to make sure that the retort shall be heated evenly throughout its length, the tube furnace employed is a platinum-wound resistance furnace, which, with a current of a little over 1 ampère at 200 volts, can attain a temperature of

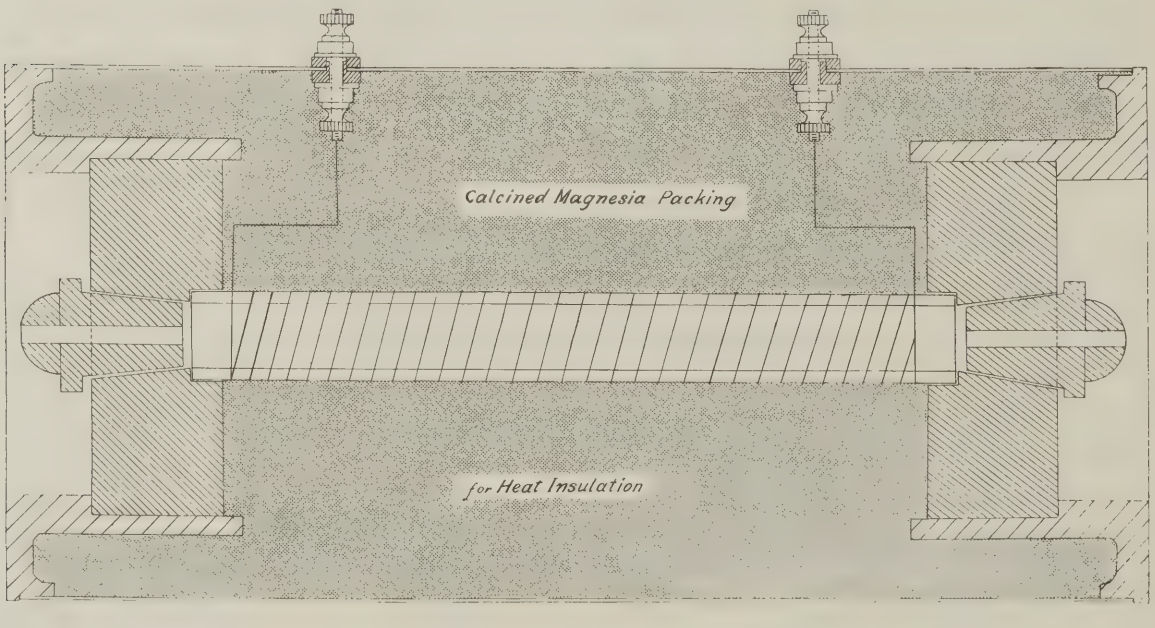


Fig. 46.—Diagram of Electric Resistance Tube Furnace, showing Method of Winding.

1,400 degs. Cent. By the introduction of suitable resistance in the electric circuit any temperature down to 100 degs. Cent. or less can be obtained and maintained for any length of time.

The form of winding and heat insulation which has been employed in general for all the furnaces designed for this work is shown in fig. 46.

The temperature of the furnace was tested by means of a thermo-couple and galvanometer for each centimetre of its length to make sure that the coal was in the zone of highest and of constant temperature when the retort was inserted. The

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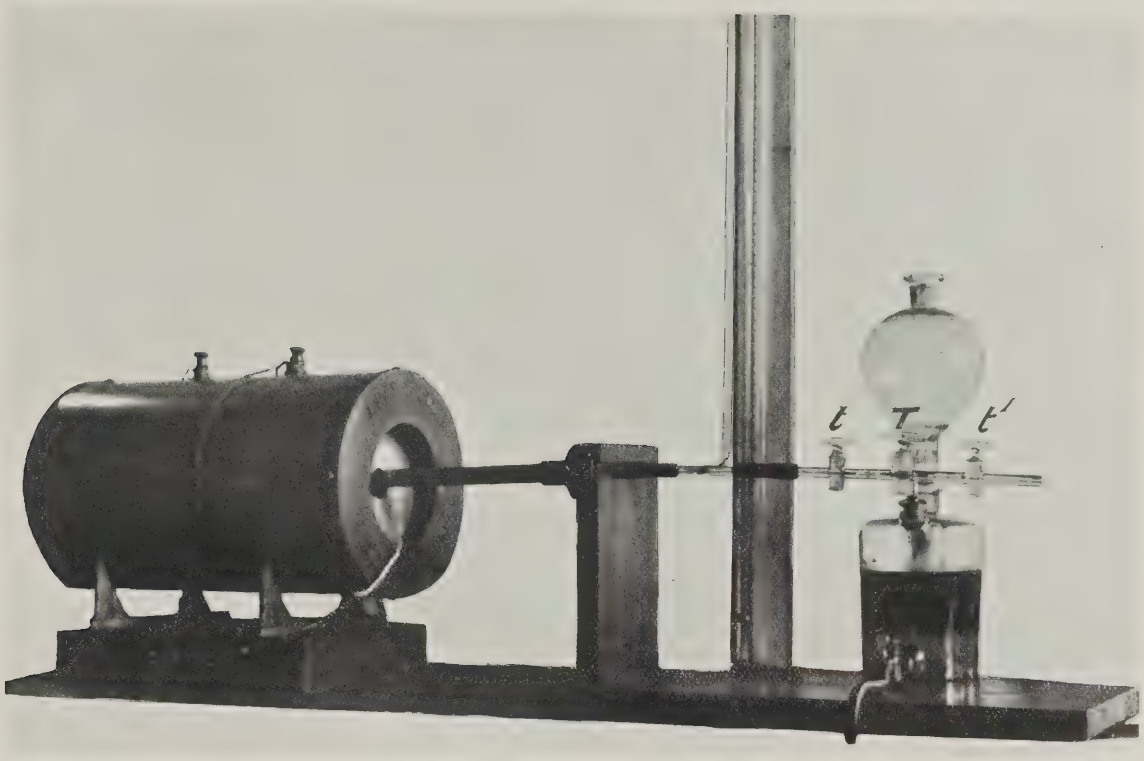



Fig. 44.—General arrangement for the Distillation of Coal.

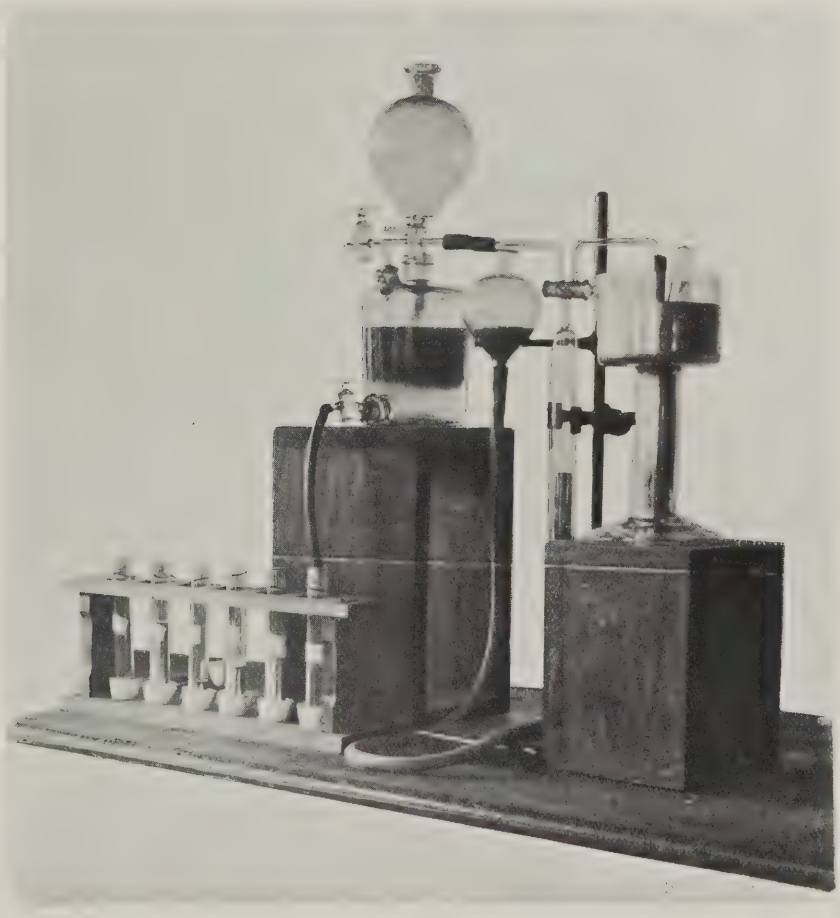
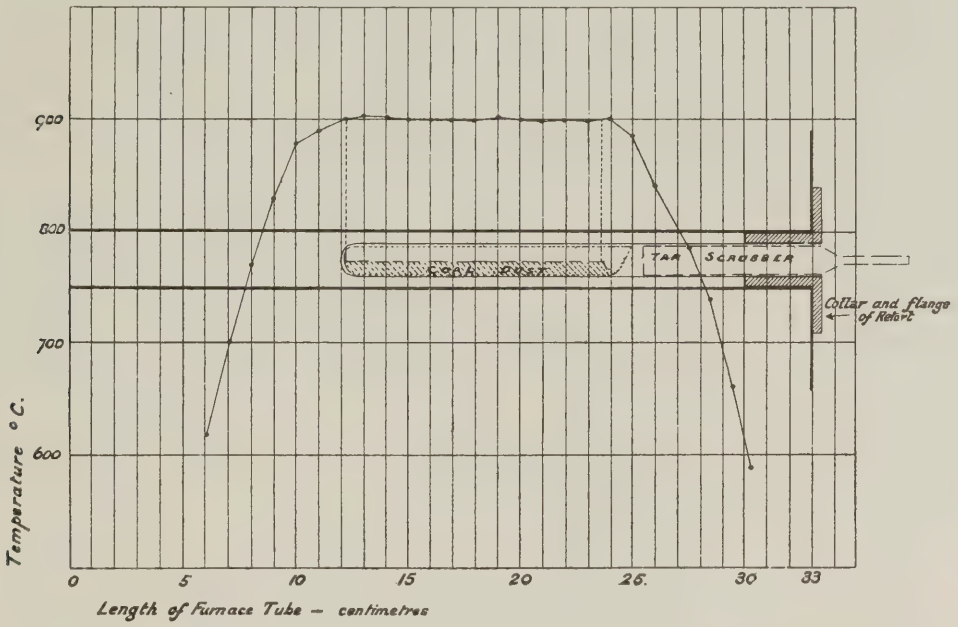


Fig. 45.—Method of Storing Gas Samples and of Transferring Gas from one Vessel to another.

result is shown in graphic form in fig. 47, the position that the retort occupies during an experiment being indicated by dotted lines. It will be seen that the length of the furnace occupied by the coal is at a satisfactorily uniform temperature, and that the end containing the tar-scrubber is comparatively cool.




Total Length of Furnace Tube = 33 centimetres.
Length of Platinum Retort = 21·5 ,,
Length of Platinum Boat = 13·0 ,,
Length of Platinum Tar-scrubber = 8·0 ,,

Fig. 47.—Diagram showing Position of Retort in Electric Tube Furnace. The Coal Dust is in a Zone of Even Temperature throughout.

### The Temperature.

The temperature is measured during an experiment by means of a platinum, platinum-rhodium thermo-couple which runs through the whole length of the furnace (the junction being in the centre), and is insulated by an unbroken length of thin silica quill tubing. A thread recorder, made by the Cambridge Scientific Instrument Company, records the temperature on a revolving drum every half minute.

### The Gases.

The gases are collected in a glass gas-holder, filled with a mixture of equal parts (by volume) of glycerine and water previously saturated with coal gas ; the gases do not dissolve in such a mixture to any appreciable extent, and its use is preferable to that of mercury.

The following experiment shows the nature of the results obtained. It might be thought that the use of such a small quantity of coal (2 grammes) could hardly be expected to give uniform results, considering the comparatively large quantities that are experimented with ; but it must be remembered that a very good sample is obtained by the method adopted of collection during pulverisation and subsequent sieving to a uniform fineness.

## ALTOFTS SILKSTONE COAL.

A sample of the dust used in Experiment No. 48 (June 14th, 1909), was employed. The ultimate analysis was as follows :—

| | |
|---|---|
| Carbon | 80·50 per cent. (of ash-free dry coal). |
| Hydrogen | 5·45 ,, |
| Oxygen | 9·70 ,, |
| Nitrogen | 1·42 ,, |
| Sulphur | 2·93 ,, |

The dust as received contained 3·65 per cent. of moisture and 5·51 per cent. of ash.

Its calorific value, as determined by the Mahler-Cook bomb calorimeter,* was 13,500 B.T.U. per pound as received, or 14,790 B.T.U. per pound of ash-free dry coal.

Its specific gravity was 1·298 (water = 1).

Two grammes of the dried dust were taken, after sieving through a 240-mesh sieve, and mixed with 3 grammes of ignited silica sand.

The distillation temperature employed was 900 degs. Cent. (1,650 degs. Fahr.). The furnace temperature was raised to 1,000 degs. Cent. just before the insertion of the retort, which at once cooled the furnace to 900 degs. Cent., at which temperature it was maintained during the remainder of the heating. It must be noted that the temperatures recorded are those of the *retort* and not that existing *in the coal itself*.

The gas came off very rapidly during the first two minutes, about 400 cubic centimetres being collected in that time.

Gas evolved—

| | |
|---|---|
| During first 5 minutes | 445 cubic centimetres |
| ,, next 5 ,, | 35 ,, ,, |
| ,, ,, 5 ,, | 15 ,, ,, |
| ,, ,, 15 ,, | 20 ,, ,, |
| ,, ,, 15 ,, | 10 ,, ,, |
| ,, ,, 30 ,, | 5 ,, ,, |
| Total length of heating | 75 minutes |
| Total gas evolved per gramme of ash-free dry coal | 265 cubic centimetres |

Composition of gas (nitrogen free)—

| | |
|---|---|
| Benzene | 3·30 per cent. |
| Carbon dioxide | 1·65 ,, |
| Ethylene | 1·65 ,, |
| Carbon monoxide | 11·10 ,, |
| Hydrogen | 54·60 ,, |
| Methane | 22·30 ,, |
| Ethane | 5·40 ,, |
| Tarry matter per cent. of ash-free dry coal | 12·50 ,, |
| Total volatile matter per cent. of ash-free dry coal | 37·55 ,, |

In Appendix I. to this Report will be found the records of similar distillations with different samples of coal. The difference in the results obtained under the same treatment, more particularly as regards the composition of the gas evolved, is very marked.

It will be seen that rather complicated gas mixtures are obtained. This necessitated the designing of a special gas analysis apparatus, which was used, in conjunction with the Bone and Wheeler apparatus† during the major part of this and allied researches. A modification has recently been introduced in the latter apparatus which enables the complete analysis to be made with that apparatus alone.

Since the accuracy of the gas analyses is such an important factor, the Committee consider it advisable to describe as concisely as possible the apparatus used and the methods employed.

* *See* Trans. Inst. M.E., Vol. xxxiii.

† "An Accurate Form of Gas Analysis Apparatus." W. A. Bone and R. V. Wheeler. J.S.C.I. January 1908.

The general character and arrangement of the apparatus will be readily understood, with the aid of the accompanying diagram (fig. 48), by all who are familiar with the methods of gas analysis. It comprises, essentially, three parts, namely :—

1. A water-jacketed combination of measuring and pressure tubes, A and B, communicating, through the glass tap C, with the mercury reservoir D.
2. An absorption vessel F, standing over mercury in a mahogany trough G.
3. An explosion tube E, fitted with firing wires and connected with a separate mercury reservoir H.

All the glass connections between A, E, and F, are of capillary bore throughout, with suitable glass taps wherever necessary.

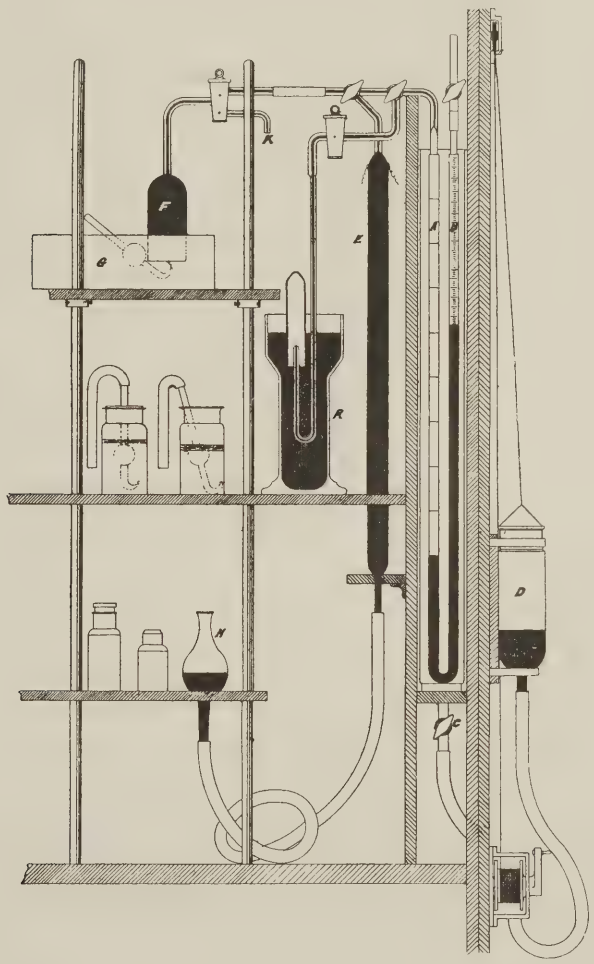


Fig. 48.—Gas Analysis Apparatus.

The gas sample is introduced into the apparatus from the wide test-tube in which it is stored (fig. 45), under the wide open end of the absorption vessel F, which has been previously filled with mercury. Before beginning the analysis, the whole of the apparatus, including all the connections between A, E, and F, is completely filled with mercury, and, needless to say, the whole of the subsequent operations are conducted over mercury.

The salient features of the working of the apparatus are as follow :—

1. The principle of measurement employed is that first introduced into gas analysis by Regnault, and subsequently adopted by Sir Edward Frankland, viz., the

measurement of the pressure of the gas (in millimetres of mercury) at constant volume. For this purpose the gas is brought to a certain "constant volume" mark on the measuring tube A (by suitable manipulation of the mercury reservoir D and the tap C), and its pressure read off on the pressure tube B. There are a series of such "constant volume" marks on A, each coinciding with a 100 mm. mark on the pressure tube B (*i.e.*, with 0, 100, 200, &c., millimetres), so that the actual pressure of the gas is given by subtracting from the pressure reading the numbers 0, 100, 200, &c., according to the particular constant volume mark selected for the analysis.

The tubes A and B are made in one piece, and are surrounded by a water-jacket, and their inner surfaces are kept moist with very dilute sulphuric acid (1 in 20) as a precaution against the accidental fouling of the measuring tube by potash, and it is obvious that the wetting of A and B with the same liquid eliminates the influence of water vapour upon the gas measurements, the various pressures representing those of the dry gas under examination.

The advantages of this mode of measurement over the more usual method of determining the volume under atmospheric pressure are two-fold : (1) it allows of the use of smaller volumes of gas for analysis—thus from 5 to 10 cubic centimetres of gas can be made to have a pressure of 100 mm. according to the particular volume mark selected, and this pressure can easily be read off to within 0·2 mm. without employing a telescope ; and (2) the measurements are, of course, independent of the barometric pressure, and at the same time are unaffected by the tension of aqueous vapour.

2. The length of the pressure tube B (about 700 mm.), amply provides for the proper dilution of the "explosive mixture" in an explosion analysis. Thus, in an analysis of a coal gas containing, say :—

| | |
|---|---|
| Carbon dioxide | 0·5 per cent. |
| Unsaturated hydrocarbons | 5·5 „ |
| Carbon monoxide | 6·0 „ |
| Hydrogen | 55·0 „ |
| Methane | 33·0 „ |

if an amount of gas were originally taken corresponding with a pressure of 120 mm. at the constant volume mark 0, then after removal of carbon dioxide and monoxide and unsaturated hydrocarbons by suitable absorbents, the residual 105·6 mm. of hydrogen and methane would give 217·8 mm. of explosive mixture when mixed with sufficient oxygen for their complete combustion, and could be diluted with the 350 mm. of *excess* oxygen necessary to ensure accuracy in the subsequent explosion.

3. The arrangement for the various "absorptions" is simple. Instead of using a number of large absorption vessels each containing a particular reagent, which is used unchanged many times over in successive analyses, all the absorptions are carried out over mercury in the one absorption vessel F, in each case with a comparatively small volume of the particular reagent, which is always used fresh and is at once discarded after use. From 2 to 5 cubic centimetres of the reagent are introduced into the absorption vessel (previously filled with mercury) by means of a suitable pipette, from beneath the surface of the mercury in the trough. Any minute bubbles of air accidentally introduced with the reagent can be got rid of by cautiously opening the branch K of the tap at the top of the absorbing vessel which leads to an exhausted bottle. The same device allows of the complete withdrawal

of the reagent after use, without taking down the absorption vessel, and also of the rinsing out of the latter *in situ* with water or dilute sulphuric acid, before the next reagent is used.

## Method of Analysis.

The gas mixtures arising from the distillation of coal at different temperatures may contain :—

| | |
|---|---|
| Ammonia | $NH_3$ |
| Benzene | $C_6H_6$ |
| Carbon dioxide | $CO_2$ |
| Acetylene | $C_2H_2$ |
| Ethylene | $C_2H_4$ |
| Carbon monoxide | $CO$ |
| Hydrogen | $H_2$ |
| Methane | $CH_4$ |
| Ethane | $C_2H_6$ |

besides traces of oxygen, nitrogen, and higher homologues of the paraffin series ($C_nH_{2n+2}$), such as propane ($C_3H_8$). Although, possibly, only the carbon dioxide and monoxide, hydrogen, methane and ethane have any great significance, it is necessary and desirable to separate each of the constituents named in the list.

The first six can be separated by suitable absorbents in the order given, thus :—

| Gas. | Absorbent. |
|---|---|
| Ammonia | Dilute sulphuric acid (10 per cent.) |
| Benzene | Concentrated sulphuric acid (1·9 specific gravity) |
| Carbon dioxide | Caustic potash solution |
| Acetylene | Ammoniacal silver chloride solution |
| Ethylene | Bromine water |
| Carbon monoxide | Ammoniacal cuprous chloride solution. |

When these have been removed, and the percentage of each determined, there remain only hydrogen, methane, ethane and nitrogen.

There are no suitable liquid absorbents for these gases, so that no direct estimation of them can be obtained. If the residual gases consisted solely of hydrogen, methane and nitrogen, then determination of the quantity of each present could easily be ascertained from (1) the change in volume, and (2) the amount of carbon dioxide produced, when the mixture is exploded with excess of oxygen, for the chemical reactions involved can be expressed in the form of readily-solved equations.*

---

* Thus, if the total contraction in volume after explosion be represented by the letter C, and the total amount of carbon dioxide produced (as determined by absorption with caustic potash) by the letter A, then

1. For the combustion of *one volume* of hydrogen according to the equation :-

$$2H_2 + O_2 = 2H_2O$$

2 vols. 1 vol. *Nil* (condenses)

Contraction of volume = 3/2 hydrogen

Carbon dioxide produced = *Nil.*

2. For the combustion of *one volume* of methane :—

$$CH_4 + 2O_2 = CO_2 + 2H_2O$$

1 vol. 2 vols. 1 vol. *Nil* (condenses)

Contraction of volume = 2 methane

Carbon dioxide produced = 1 methane.

Whence

3/2 hydrogen + 2 methane = C ..... (1)

1 methane = A ..... (2)

So that the quantity of methane present can be determined directly from the absorption by caustic potash after explosion (equation 2), and the hydrogen can be calculated by substituting the value thus found for methane in equation 1, so that

Hydrogen = 2/3 (C − 2A).

When, however, hydrogen, methane and *ethane* are all present, the calculation cannot be made in the same manner by using a third equation for the combustion of ethane,* for there would be three "unknown quantities" and only two simultaneous equations by which to determine them.

It is necessary in such cases first to remove the hydrogen by some means, and then to explode the residue with excess of oxygen.

The proportion of methane and of ethane present can then be calculated by means of the two equations :—†

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Methane..... | $CH_4$ | + | $2O_2$ | = | $CO_2$ | + | $2H_2O$ ..... (*a*) |
| | 1 vol. | | 2 vols. | | 1 vol. | | *Nil* (condenses) |
| Ethane ..... | $C_2H_6$ | + | $3\frac{1}{2}O_2$ | = | $2CO_2$ | + | $3H_2O$ ..... (*b*) |
| | 1 vol. | | $3\frac{1}{2}$ vols. | | 2 vols. | | *Nil* (condenses) |

It is absolutely essential that the presence of ethane should be sought for, as it will be found that the calculations are thrown entirely wrong by the presence of a small percentage of ethane,‡ if the "residual gas" remaining after the absorptions be assumed to be only hydrogen and methane.

Hydrogen can be removed by treatment with "oxidised" palladium sponge. Spongy palladium on being heated to dull redness in air undergoes superficial oxidation, and then has the property, when heated to 100 degs. Cent., of removing hydrogen and leaving methane and ethane untouched. Its action in removing hydrogen is partly oxidising and partly "occluding."

The palladium absorptions are conducted in a separate piece of apparatus, the construction of which can be readily understood from fig. 49, and the gases are transferred from the measuring apparatus by means of a side-tube attached thereto and a special mercury trough R (fig. 48).

After all traces of the various other gases present have been removed by absorbents, the mixture of hydrogen, methane and ethane is passed into the palladium bulbs, which have been previously exhausted, and are now immersed in boiling water. After heating the bulbs for about 15 minutes, and allowing them to cool, the residual

* $C_2H_6 + 3\frac{1}{2}O_2 = 2CO_2 + 3H_2O$
1 vol. $3\frac{1}{2}$ vols. 2 vols. *Nil* (condenses)
Contraction of volume = 5/2 ethane
Carbon dioxide produced = 2 ethane.

Whence

3/2 hydrogen + 2 methane + 5/2 ethane = C .. .....(1)
1 methane + 2 ethane = A .....(2)

† For, according to (*a*) contraction of volume = 2 methane
carbon dioxide produced = 1 methane
and, according to (*b*) contraction of volume = 5/2 ethane
carbon dioxide produced = 2 ethane.

Whence

2 methane + 5/2 ethane = C .....(1)
1 methane + 2 ethane = A .....(2)

So that

Ethane = 2/3 (2 A − C),
Methane = 2/3 (2 C − 5/2 A), or = A − 2 ethane.

‡ For example, 62 vols. of gas gave, after explosion with excess of oxygen, C = 87·8 and A = 29·2. If it is assumed that the combustible gases consist solely of hydrogen and methane, the calculated percentages of these two gases would be :—Hydrogen = 31·6 per cent., and methane = 47·10 per cent. As a matter of fact, the gases contained 8·15 per cent. of ethane, which caused the correct quantities of hydrogen and methane to be 44·75 and 30·30 per cent. respectively.

Ethane exists, in quantity up to 5 per cent., in many samples of ordinary lighting gas, a fact which appears to have escaped general notice.

gases are withdrawn by means of a mercury vacuum pump and transferred to the measuring apparatus. Any contraction in volume observed is due to the removal of hydrogen, which can thus be determined directly. An explosion analysis is then made in the usual manner, and the proportions of methane and ethane calculated.*

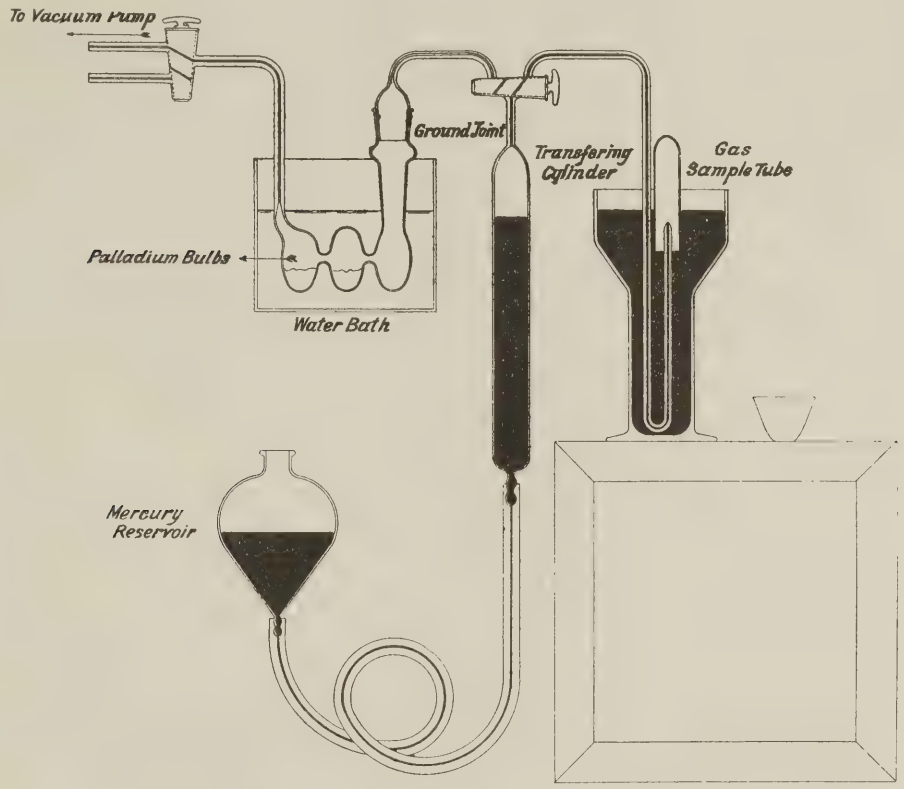



Fig. 49.—Palladium Absorption Apparatus for Hydrogen Determination.

The results obtained by this method of conducting analyses are accurate to within 0·02 per cent.

* The value obtained for ethane may be liable to slight error due to the presence of traces of the higher homologues which cannot be estimated conveniently.

## CHAPTER V.

# THE "BRITISH COAL DUST" INSTRUMENTS FOR INVESTIGATING THE MODE OF PROPAGATION OF COAL DUST EXPLOSIONS.

CHAPTER V.

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# THE "BRITISH COAL DUST" INSTRUMENTS FOR INVESTIGATING THE MODE OF PROPAGATION OF COAL DUST EXPLOSIONS.

In order to be able to study dust explosions from a fundamental standpoint, accurate data, under known conditions of experiment, are required concerning—

1. The pressure developed,
2. The velocity with which the flame and the pressure are propagated,
3. The composition of the products of combustion, and
4. The temperature attained during explosive combustion.

To allow of comparison between one experiment and another, or to arrive at a complete understanding of what is occurring in any individual experiment, it is essential that there should be as little variation as possible in the conditions existing at the time of explosion, and that a homogeneous mixture of dust and air in definite proportions should be obtained in each case. The obtaining of a homogeneous mixture, though a comparatively simple matter in the case of two gases, is beset with difficulties when fine dust and air form the explosive mixture to be experimented with. Preliminary trials have, however, indicated a method by which it is hoped that this difficulty may be overcome and which will be fully described in a future report. The manner of obtaining the dust and air mixture employed in the experiments recorded in this report has already been described in Chapter II.

The instruments for recording the various data required are fixed on the outside of the Experimental Gallery, and their positions can be varied to suit different experiments. They are put into action electrically and are all controlled from the firing station (*see* Plate III).

## THE MEASUREMENT OF PRESSURE.

In dealing with momentary high pressures, suddenly developed, means of registration must be adopted which, from the nature of things, may be open to slight inaccuracy ; for all the methods of *continuously* recording pressure that can be devised depend upon some mechanical contrivance which can be caused to register its movement, under the action of the pressure developed, upon some form of chart. This being so, a mechanical error is introduced by reason of the inertia of the moving parts, which, under a sudden impulse, will tend to show a higher result than is strictly true.

The measurement of the *maximum* pressure attained is comparatively simple. The instrument that would appear to be most suitable for this purpose is the so-called "crusher" gauge, first used by Sir Andrew Noble in his researches on gunpowder. All such instruments as this are based upon the measurement either of

the depth of indentation made upon a copper or lead disc by a steel punch attached to a piston, this piston being driven into the disc by the force of the explosion, or of the amount of crushing of a copper or lead cylinder.

It was considered more important to try to estimate not only the maximum force developed, but also to obtain a continuous-pressure curve which would be traced during the whole time that the explosion lasted. The existing types of recording manometer failed for this purpose for the reason already stated, their moment of inertia being too great, so that it became necessary to design an instrument especially for this work. From preliminary observations during the earliest experiments the conclusion was arrived at that pressures as high as about 300 lb. per square inch, developed probably in a small fraction of a second, would have to be recorded. This being the case, it was very important that the natural period of vibration of the moving parts of the manometer should be short, otherwise the instrument would merely record the vibrations transmitted to it by the sudden shock of the explosion, and actual fluctuations in the pressure itself would be obscured.

In order to obtain a short period, the weight of the moving parts had to be made as small, and the tension of the spring had to be as great, as possible.*

There is, of course, a limit beyond which it was impossible to go in either direction. On the one hand, the fact that the instrument would have to withstand a pressure of from 200 to 300 pounds per square inch suddenly applied, made the strength of the materials employed in its construction of paramount importance, so that it was impossible to reduce the weight of the moving parts by using a metal of low density, nor could their size be reduced below a certain minimum. On the other hand, the amount of deflection of the spring had to be sufficiently great to enable accurate measurement of the record to be made, so that too great a tension had to be avoided.

### The B.C.D. Manometer or Pressure Recorder.†

In the manometer as finally designed (fig. 50), strength has been ensured by employing a plate of tempered steel as the spring. This plate is triangular in shape, and is clamped at its base, while the force acts vertically upwards at its apex, which carries a fine steel point or "scribing style." With this form of spring the maximum strain is the same at all cross-sections, and the inertia is reduced, since it is the narrow part of the spring which moves most, and the wide part least.

The pressure is transmitted by a cushion of oil to a cylindrical plunger P (fig. 51), which can move freely in a vertical direction in a hollow cylinder. The oil keeps the plunger well lubricated, reduces leakage past it, and prevents the fine dust with which the compressed gases are charged, from cutting or clogging the rubbing surfaces; the oil-box also acts as a dash-pot by damping out any rapid vibrations. The plunger is made hollow for the sake of lightness, and makes contact with the spring S by means of a loose connecting-rod R, one end of which rests in a conical

* The periodic time T can be calculated from the equation $T = 2\pi\sqrt{\frac{W}{Ag}}$, where W is the weight of the moving parts, and A represents the force required to produce unit deflection of the vibrating system. A short period is therefore obtained by making the former a minimum and the latter a maximum. (*See* also Lord Rayleigh's "Sound," Vol. I.).

† The letters B.C.D. (the initial letters of the words "British Coal Dust") are prefixed to the names of all instruments that have been specially designed for this investigation.

depression in the bottom of the plunger, and the other end in a similar depression in the spring. A secondary weak spring S′ acts upwards on the plunger, so as to ensure contact between the ends of the rod and the conical depressions, even when there is no pressure on the plunger. This method of connection allows the plunger to be free to take up its correct position laterally in the cylinder. The scribing style which is attached to the end of the manometer spring presses lightly against the surface of a smoked paper band revolving on a drum D (fig. 52), driven by an electric motor. The speed at which the smoked paper is revolving during an experiment is recorded near the top by means of a $\frac{1}{10}$ second time-marker of special construction. After the experiment the smoked paper is removed, and the surface fixed by immersion in a bath of transparent spirit varnish.

The amount of upward movement of the point of the spring equivalent to a pressure of 20 lb. per square inch above atmospheric pressure is only about $\frac{1}{20}$ in., so

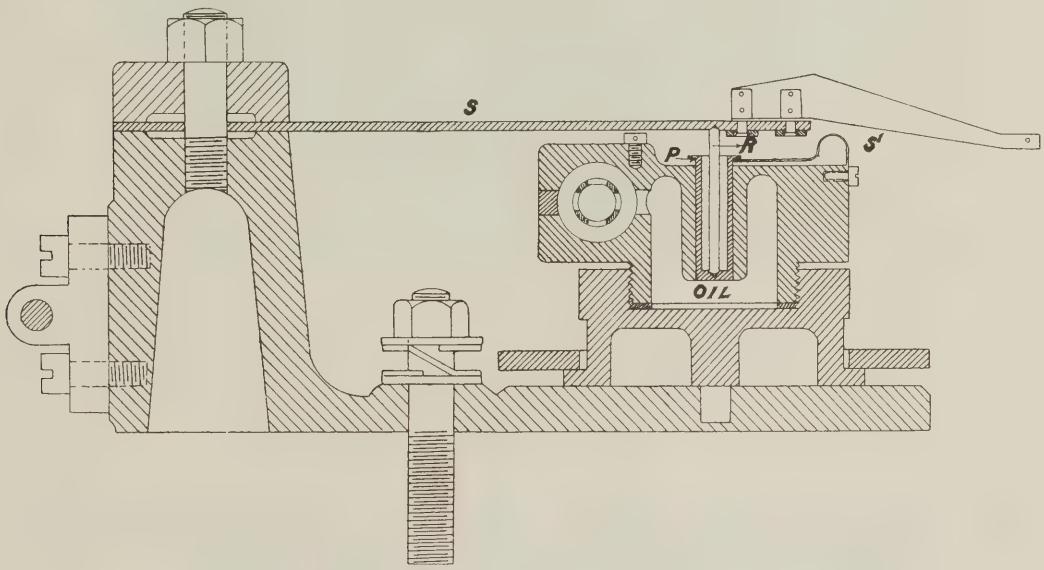



Fig. 51.—Manometer.—Section through Oil Box.

that it is necessary to employ a microscope when measuring the record traced by the scribing style.

The pressure inside the experimental gallery is transmitted to the manometer by means of a flexible connecting pipe joining the instrument at P (fig. 52) ; this pipe has a ball and socket joint at each end, and also a sliding joint giving complete freedom of movement so as to absorb any vibration that might be transmitted from the boiler plates forming the experimental gallery.

In order to compare one pressure record with another, further data are required. To measure the rate at which successive waves of pressure pass along the gallery the relative position of each manometer drum at the time the explosion started must be recorded, and the speed of revolution of each drum must also be known. Deprez indicators, I (fig. 50), are used for this purpose, two being attached to each manometer. This form of indicator consists of a small electro-magnet which, so long as a current passes through it, holds down against the pull of a weak spring a light aluminium style, which rests against the smoked surface of the manometer drum. As soon as the electric circuit is broken, the style is released and moves up, tracing a vertical line on the smoked surface.

One indicator on each manometer is connected in series with the next, and the electric circuit is completed through a fine wire stretched across the gallery at the

point of ignition of the explosion. This wire is broken as soon as the explosion is started, so that a mark is made on each drum at that moment.

The second indicator on each manometer records the speed of revolution of the drums ; they are connected in series with the " tenth-of-a-second time-marker " described below.

The drums of the manometers are driven by electric motors at a uniform speed

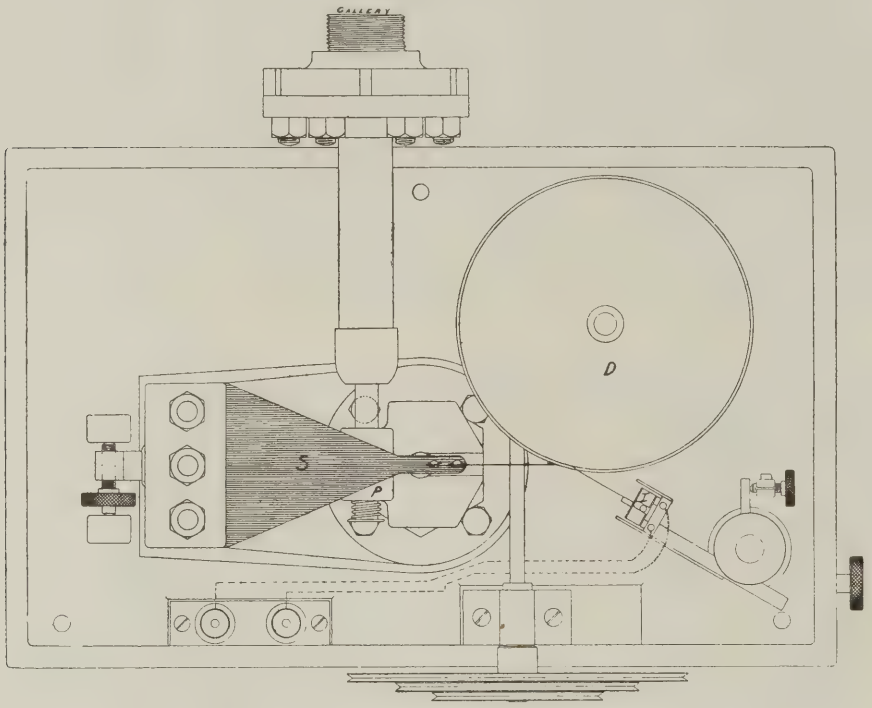
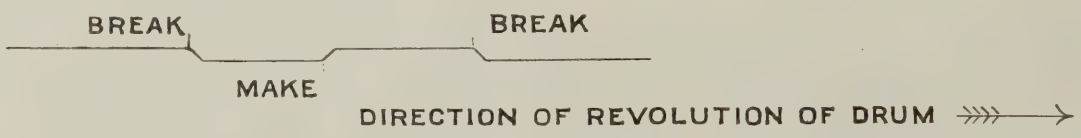



Fig. 52.—Manometer.—Plan showing connection to Gallery.

by means of a 100 volt circuit from a dynamo run specially for these and other similar instruments where a current of constant voltage is required.

## The B.C.D. Time Marker.

One of the most accurate methods of obtaining a measurement of time of constant value is to record the time taken for a body to fall from rest through a standard distance. Advantage of this fact has been taken in designing the tenth-of-a-second time-marker used for measuring the speed of revolution of the manometer drums. A weight W (fig. 53) is so arranged that when at rest an electric current is passing through it ; as soon as its support is withdrawn the circuit is broken ; while still falling, contact is again made, to be broken again when the weight reaches the end of its fall. In this manner, when the time-marker is connected in series with the Deprez indicators on the manometers, there are successively a break, a make, and a break, traced by the styles on the drums : the record thus takes the following form :—




It is the distance between the two *breaks* of circuit that must be measured, since this distance is equivalent to the time taken for the weight W to fall through the standard distance from rest. This distance is calculated from the dynamic formula $s = \frac{1}{2} g t^2$ so as to give a time interval of exactly $\frac{1}{10}$ second.

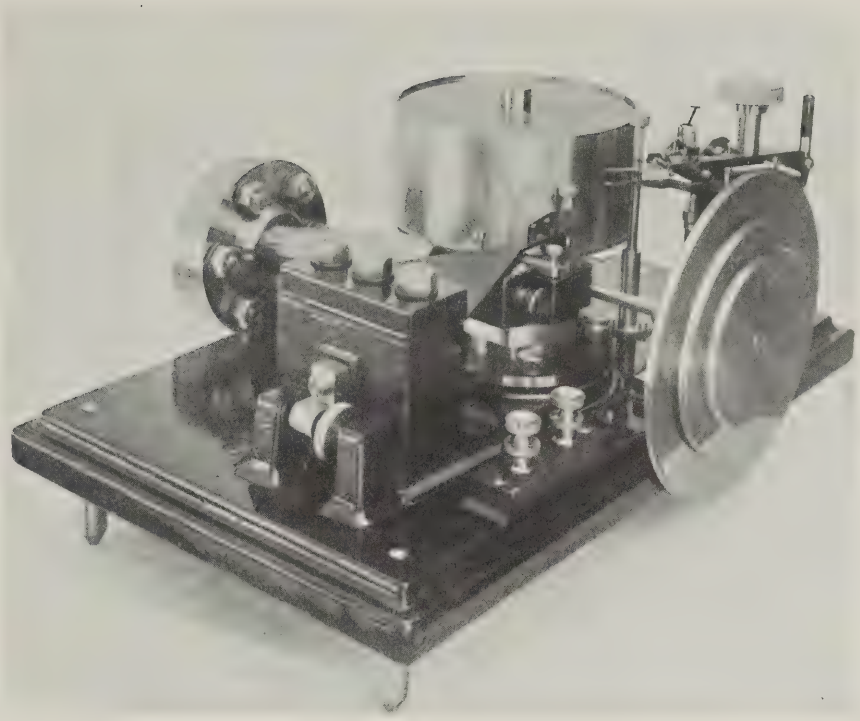


Fig. 50.—The B.C.D. Manometer. By means of this Instrument a continuous Record of the Pressure developed is obtained. Several of these Manometers can be attached at different points along the Gallery so as to enable the course of the Explosion to be investigated.

Fig. 53.—The B.C.D. Time-marker. An accurate unit of time (one-tenth of a second) is obtained by means of this Instrument.

The reason for measuring the distance between two breaks of circuit, instead of between a break and a make, which would have been simpler to arrange, is that after the circuit is broken a short interval of time elapses before the core of the electro-magnet becomes demagnetised ; on the other hand, when the circuit is made again, there is another short interval before the magnet can attract its armature. These two intervals of time, though both very small, are not identical, and to avoid having to introduce a correction for this, it was thought better to arrange for two breaks, so that, since both would be influenced by the same latency, direct measurement of the distance between them would give a correct time interval.

The manner in which these two breaks are obtained is as follows :—The weight W rests freely on brass knife-edges in V's cut in the support S, which can pivot about its centre ; while thus supported the electric circuit is complete and the current is passing through the electro-magnets on the manometers. As soon as the catch C is released, the support is withdrawn by the spring T, and the weight is free to fall ; the strength of this spring is such that the end of the support moves more quickly than the weight begins to fall ; the support thus gets well out of the way of the brass knife-edges on the weight rod, and the current which was passing through is broken at the instant that the weight begins to fall. While the weight is still falling, the opposite end of the support flies up and becomes jammed between two brass clips A, A on the top of the standard, and completes the circuit again. This occurs after the weight has fallen about two-thirds of its distance, then, as soon as the weight hits the polished steel platform P, the circuit is again broken, the impact separating two platinum contacts beneath the platform.

The distance through which the weight must fall can be adjusted to the standard distance by screwing the weight up or down the rod.

By means of suitable electrical connections the weight is caused to fall by the action of the explosion itself, so that the time interval is recorded at the same time as the pressure curve.

### The B.C.D. Measuring Apparatus.

The smoked paper, with the pressure curve and time interval recorded on it, is removed from the manometer drum by cutting it with a knife along one side, care being taken to part the paper at a point where it will not damage the valuable part of the curve. It is then fixed by placing it in a bath of weak varnish, and when dry is ready for mounting on the measuring machine.

The drum D in this machine (fig. 54) is a little larger than the drum of the manometer, and the ends of the paper chart do not meet on it but are held down by clips *c*, *c*. The axis of the drum rests in V supports, in which it can rotate or slide laterally. The drum itself is divided round its circumference into millimetres, and the distance between any two points on the chart is measured by means of a vernier, the drum being revolved while observing the chart through the microscope M. The readings can readily be made to $\frac{1}{10}$ mm., so that, since the time interval of $\frac{1}{10}$ second marked on the chart is usually about 60 mm. long, it will be seen that a period of time of less than $\frac{1}{6000}$ second can be measured with great accuracy.

By means of a micrometer screw S with a divided head, the drum can be moved laterally so as to enable the pressure curve to be investigated. The reading corresponding to the zero-line is taken for any point on the curve by means of fine

cross-wires in the eye-piece of the microscope, and the micrometer screw is then moved until the point whose distance from the zero line it is required to measure appears in the centre of the field of the microscope (as indicated by the cross-wires); the distance traversed is then read off on the micrometer head, and at the same time the corresponding reading on the circumference of the drum is noted. In this manner it is possible to trace completely the movement of the manometer style as recorded on the smoked paper, and to obtain an exact measurement of fluctuations of pressure during different time intervals. When the curve is a smooth one, the pressure rising gradually to a maximum and then falling evenly, only a few points need be defined, but where the curve is irregular and shows signs of rapid changes of pressure, a hundred or more points have to be read in order to be able to reproduce the curve exactly.

The distances on the manometer records corresponding to successive increments of pressure are checked from time to time by recording known pressures on a separate chart, which is afterwards used as the standard of measurement. For this calibration, pressures up to 400 lb. per square inch are obtained by means of a Schäffer and Budenberg dead-weight pressure-gauge tester and standard gauge (fig. 55).

## THE MEASUREMENT OF VELOCITY.

There are three distinct ways in which it should be possible to obtain a record of the speed at which an explosion is travelling, corresponding with the three phenomena that accompany the explosion—heat, pressure and light. Since the speeds of propagation of all three are interdependent, light being the outcome of the intense heat, and the pressure being developed by the expansion of the gases by the heat of combustion, a determination of the speed of travel of any one of these three observable effects of an explosion should give the velocity of propagation of the explosion itself.

However, in spite of the apparent variety of methods available, the accurate determination of the velocity has been attended by great experimental difficulties due chiefly to the great speed attained by the explosion, coupled with the necessity for determining this speed between several points comparatively close together.

The underlying principle of the methods that have been adopted has been to allow the explosion to break a series of electric circuits placed at fixed intervals along its path. The graphic record of the destruction of each circuit has been obtained in a similar manner to that already described in connection with the time-marker for the manometers, namely by the unmaking of a small electro-magnet which allows a light style attached to its armature to trace a line on a suitable surface travelling at a known speed.

### The Circuit Breakers.

(*a*) *The Tin-foil Circuit Breaker.*—Separate electric circuits are completed within the gallery by means of small strips of tin-foil 4 in. long by $\frac{1}{2}$ in. broad, such circuits being placed every 50 ft. from the point of ignition of the explosion. A piece of tin-foil of this size, if placed with its edge offering the least resistance to the explosive blast, remains unbroken by the firing of the charge of blasting-powder that is used to effect ignition of the coal dust, but is immediately melted

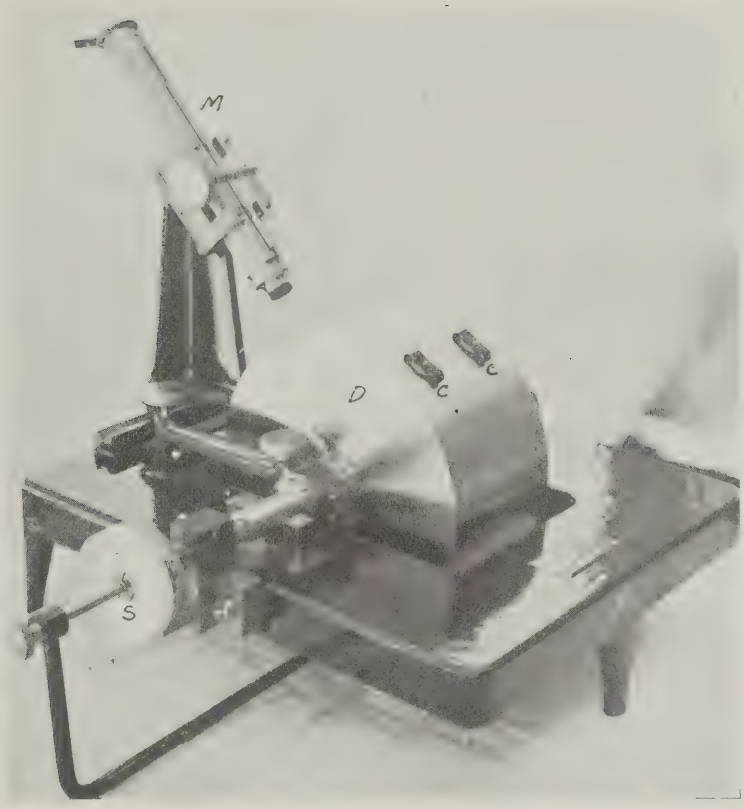



Fig. 54.—The B.C.D. Measuring Apparatus. For examining the Pressure Curves. The standard interval of time used for determining the rate of propagation of pressure during the explosion can easily be read, by means of this instrument, to $\frac{1}{6000}$th of a second.

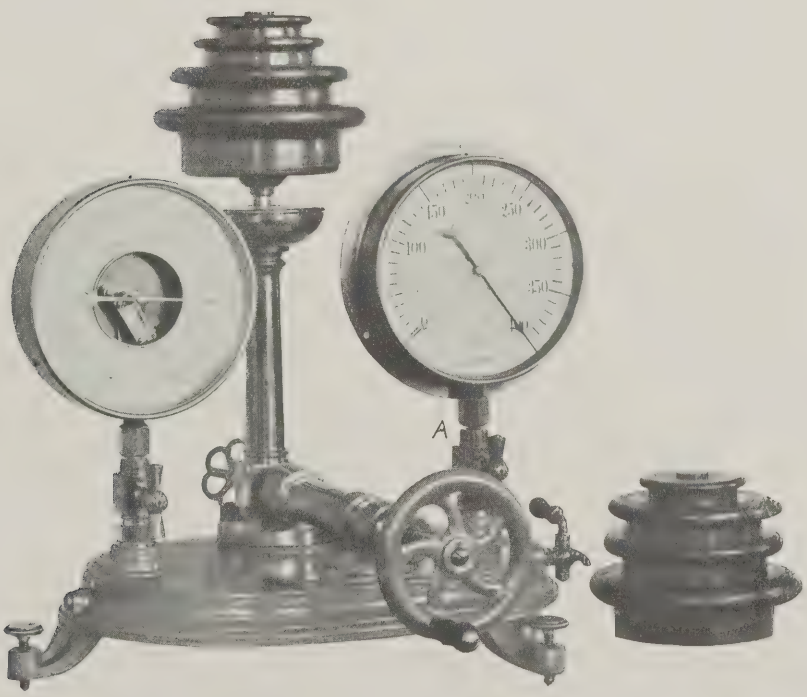



Fig. 55.—Standard Pressure Gauge Tester for testing Manometers. The Manometer is connected at A in place of the Gauge shown in the photograph.

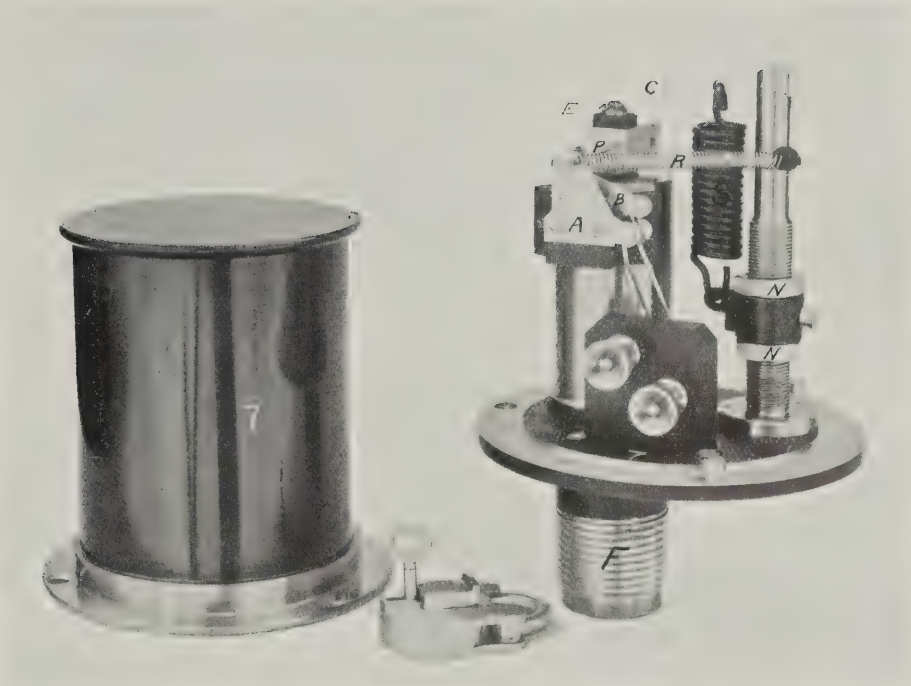



Fig. 56.—The B.C.D. Circuit Breaker. Before firing.

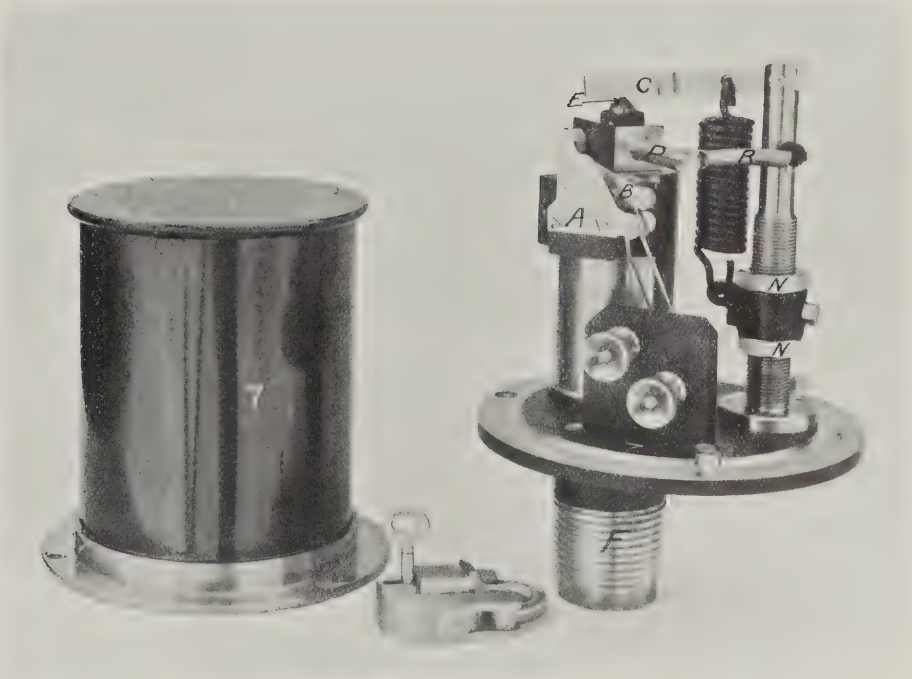



Fig. 57.—The B.C.D. Circuit Breaker. After firing.

by the flame of the explosion. For a certain distance, therefore, these circuit breakers serve to record the rate of passage of *flame*, in contradistinction to the rate of passage of *pressure*, for which latter purpose another instrument is employed.

The source of electric current for each circuit is a separate 4 volt accumulator, the resistance of the lengths of wire necessary to connect the tin-foil strips in the gallery to the recording instrument in the observatory being sufficient to reduce the E.M.F. to 1 volt across the terminals of the electro-magnet used to register the breaks in circuit.

(*b*) *The B.C.D. Circuit Breaker* (*Moving Piston*).—This form of circuit breaker is used to measure the rate of travel of *pressure* along the gallery, and is arranged so as to act only when a definite pressure has been exceeded, so that it is not moved prematurely by the firing of a charge of blasting powder.

A hole is drilled and tapped into the roof of the gallery, and the tube F (figs. 56 and 57) is screwed into it; this tube is connected to a cylinder containing a plunger, the top of which is seen at E. The plunger is pressed down by the lever C and the spring S, the tension of which can be so adjusted by the lock-nuts N, N that the force required to lift the plunger can be fixed at from 2 to 20 lb. per square inch as required. Fig. 56 shows the instrument before the explosion has reached it and fig. 57 after the explosion has broken the circuit. A horizontal pin P projects from the plunger and rests on two brass plates A and B, completing an electric circuit between them; a horizontal spring R acts on the outer end of the pin and tends to make the plunger rotate; this rotation is prevented by the plates A and B, their shape being such that the pin pressing downwards must press on both of them, while as soon as the explosion raises the plunger, the contact is at once broken and the spring R pulls the pin sideways, thus preventing any remake of circuit when the plunger falls again.

## The Recording Instruments.

It was very important that, whatever form of instrument was used for registering the series of breaks of electric circuit, the same electro-magnetic style should be employed for recording each break. For although the error due to latency or "time-lag" is extremely small in the delicate Deprez indicators employed (the armatures carrying the aluminium styles can readily be moved by a current of 0·1 ampère at 1 volt), the time intervals to be recorded are themselves only a small fraction of a second, so that the *percentage* error might be considerable were separate electro-magnets, each having a different latency, employed.

An instrument, which can be termed an "automatic commutator," was therefore designed to enable each successive break in circuit to be recorded by the same electro-magnet.

*The B.C.D. Automatic Commutator.*—This instrument, a photograph of which is given in fig. 58, is used in conjunction with the recording instruments (chronographs), described later.

One terminal of the battery supplying the electric current is connected to the brush G of the commutator (fig. 59), and a lead from the other terminal of the battery takes the current to the electro-magnet on the chronograph, so that its armature is attracted. The current then passes by a lead to the electro-magnet on the commutator, and that armature is also attracted; the lead taking the current

then goes to one terminal of all the circuit breakers in the gallery one after the other; the second terminal of all the circuit breakers is connected to the studs marked 1, 2, 3, 4, &c., on the commutator by separate leads, No. 1 circuit breaker (the one nearest the point of ignition) being connected to No. 1 stud, No. 2 circuit breaker to No. 2 stud, and so on. Supposing the brush G to be resting on No. 1 stud (the position that it occupies at the beginning of an experiment) the current is then flowing through the chronograph electro-magnet, the commutator electro-magnet, and No. 1 circuit breaker; then, through the brush G, back to the battery. Suppose now that the explosion passes along the gallery and breaks the circuit at No. 1 circuit breaker; the chronograph electro-magnet releases its armature, and the pen it carries makes a mark on the moving surface; at the same time the armature D of the commutator electro-magnet is released and the anchor escapement A is moved, since it is attached to the armature. This allows the spring S to pull the scape wheel B round by the cord K, which is wound on a drum attached to the axis of the scape wheel. The brush G then moves on to stud No. 2, and the current at once begins to flow through circuit breaker No. 2, the chronograph electro-magnet, and

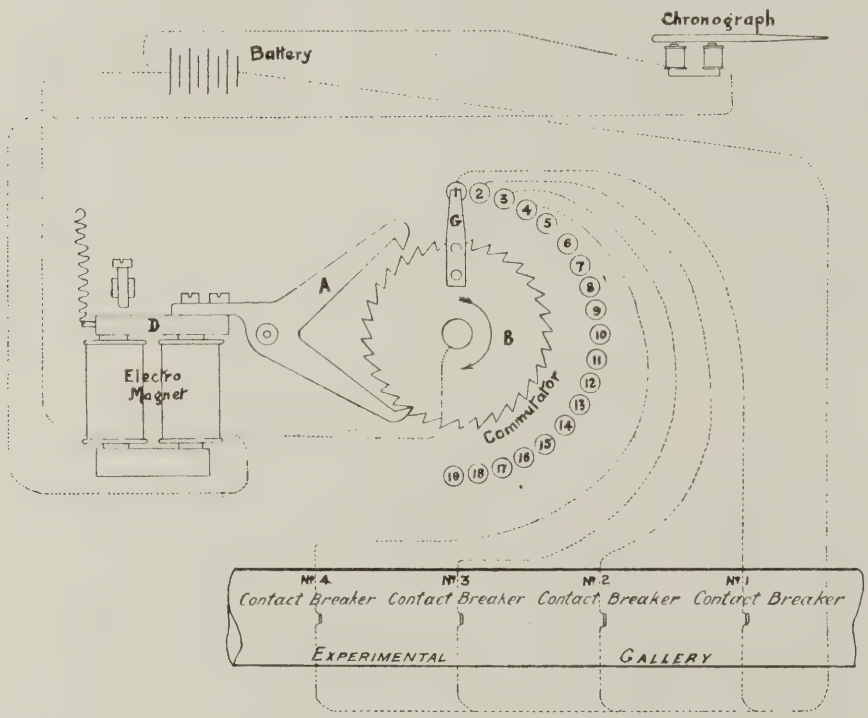



Fig. 59.—Diagram showing connections to automatic commutator for velocity determinations.

the commutator electro-magnet, and the armatures of both these are again attracted; the pen on the chronograph is moved back to its former position, as also are the armature D and the escapement A, while the brush G moves a little further on to stud No. 2. When the explosion reaches No. 2 circuit breaker, the same cycle is repeated, and so on for as many points as may be fixed, all the breaks in circuit being recorded by the one pen on the chronograph. With this instrument it is possible to record velocities of 3,000 ft. per second between successive points, each 50 ft. apart.

The record of the velocity has always been obtained by two different methods in order to have a satisfactory check on the result obtained; in the one case the record is traced in ink upon a long riband of paper moving horizontally, and in the other a smoked paper band is used, revolving on a drum as with the manometers.

Fig. 58.—The B.C.D. Automatic Commutator. For enabling the velocity of the explosion, between several points along its path, to be recorded. A maximum speed of 3,000 ft. per second, between each of nineteen points 50 ft. apart, can be recorded.

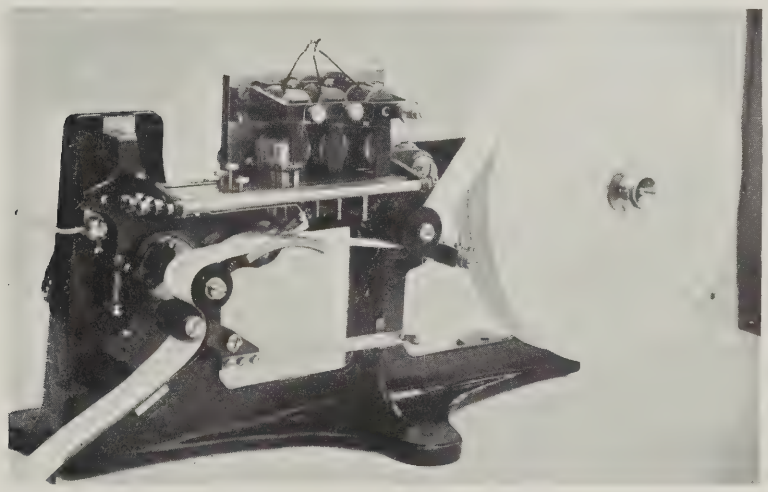


Fig. 60.—Chronograph No. 1. The Laboratory Chronograph of the Cambridge Scientific Instrument Company.

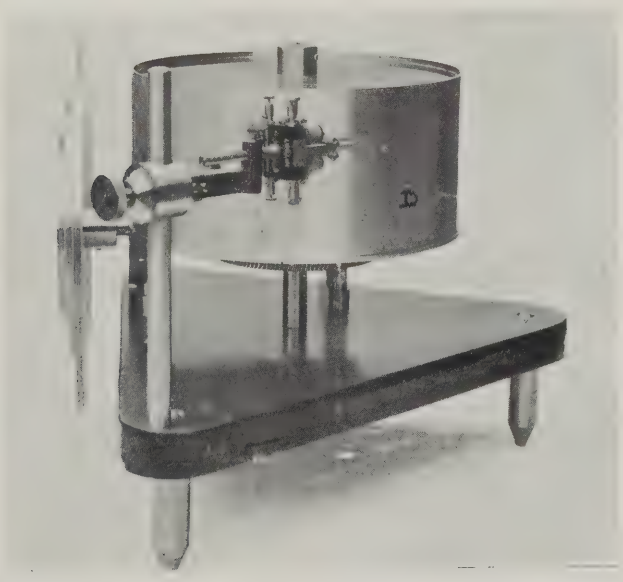



Fig. 61.—Chronograph No. 2. The B.C.D. Chronograph.

*Chronograph No. 1.*—The Laboratory Chronograph of the Cambridge Scientific Instrument Company (fig. 60). It comprises three electro-magnets M, to the armature of each of which a fine-pointed glass pen is attached, which moves with the armature according as the electric circuit through the magnet is made or broken. The pens rest lightly on the surface of a narrow riband of paper (such as is used in the Morse telegraph receiver), which can be drawn along at a uniform speed by an electric motor. The electro-magnet carrying one of the pens is connected in series to a 4-volt accumulator and a "contact-clock" which breaks circuit every half-second, thus giving the speed of travel of the paper. The second electro-magnet is connected, as described, to the commutator, and the pen it carries records the various breaks in circuit that may occur. The third is held in reserve.

*Chronograph No. 2—The B.C.D. Chronograph.*—A heavy drum D (fig. 61), which can be revolved at a uniform speed by means of an electric motor, has a paper band attached to it, on the smoked surface of which two Deprez indicators rest lightly. One indicator is connected to the tenth-of-a-second time-marker and serves to record the speed of revolution of the drum, while the second is connected to the commutator and records the breaks in electric circuit caused by the explosion as it travels along the gallery.

## THE PRODUCTS OF COMBUSTION.

A knowledge of the composition of the products of combustion during a coal dust explosion is of great importance for an understanding of the manner in which the explosion is being propagated. Just as in a gaseous explosion, there must be a preliminary period in the development of a dust explosion during which the mixture of dust and air is being heated up to its ignition point, when distillation of gases from the dust can take place. If the rate at which this distillation proceeds is sufficiently rapid compared with the speed at which the explosive combustion is proceeding, a sample of the gases taken during this preliminary period, *i.e.*, immediately prior to the actual explosion, should contain traces of the distilled gases.

The question whether combustion of the particles of coal dust as a whole has occurred, or whether the volatile constituents of the coal dust play an important part in propagating the explosion (beyond determining the ignition point of the dust), can be determined from the relation between the nitrogen and the products of combustion in a sample taken just after the flame has passed.

The essentials of an apparatus for obtaining samples capable of giving such information are :—

(*a.*) The exact moment at which the sample of gas is withdrawn in the course of the explosion must be known and must be capable of alteration at will. Thus the opening and closing of any sampling arrangement cannot be left to personal control, but must be automatically operated by the explosion itself.

(*b.*) The sample must not be diluted by an unknown quantity of air, so that any length of connecting pipe containing air between the sampling bottle and the explosion gallery must be avoided.

(*c.*) The time during which the sample is being collected must be very short. The total duration of the explosion is not long, and the composition of the gases during successive phases will vary, so that any sampling arrangement that takes a comparatively long time to fill is inadmissible.

### The B.C.D. Sampling Bottle.

These conditions have been fulfilled in the following manner. A steel bottle B (figs. 62 and 63) is fixed outside the gallery and a steel pipe connection S projects inside for a distance of 3 ft. 9 in., 2 ft. 6 in. or 1 ft. 3 in., according as it is required to draw a sample from the centre of the gallery or from nearer the side ; this tube is closed at the end inside the gallery by a thin glass cap fastened by cement.

The whole apparatus, including the pipe connection, is now exhausted by a vacuum pump.

A " contact maker " (*see* page 81) is fixed on the gallery at any desired position relative to the sampling bottle. On reaching the contact maker the explosion causes it to complete an electric circuit, which passes to the sampling bottle and through a fine iron wire holding back a hammer placed over the glass cap. The current fuses the wire and thus allows a spring to pull the hammer down and break the cap, so that gas rushes into the exhausted bottle. Details of this arrangement are shown in fig. 64.

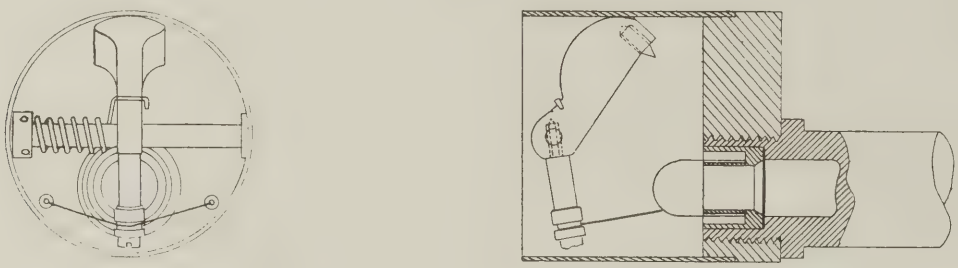


Fig. 64.—End of Sampling Bottle Tube, showing manner of breaking glass cap.

The current also passes through an electro-magnet M (figs. 62 and 63) in parallel with the fuse wire, so that at the same time as the wire is fused the armature of the magnet is attracted and releases a trigger R, allowing a small weight A to fall. Whilst this weight is falling, the gas is still entering the bottle, but after it has fallen a short distance a piece of cord attached to it, which passes over the pulley E, is suddenly jerked and a pin P is pulled out of a hole in the rod Q. This pin releases a heavy weight W connected by a cord over the pulley F, which then pulls round the tap T, thus closing the bottle.

The sample is afterwards withdrawn by means of a mercury vacuum pump and taken to the laboratory for analysis.

The length of time that the bottle remains open to the gallery can be regulated by using a longer or shorter cord attached to the small weight A.

*The B.C.D. Sampling Cylinder.*—For the purposes of chemical analysis a few cubic centimetres only of gas are sufficient, but it is desirable also to be able to trap a considerable quantity of afterdamp for the purpose of studying its physiological effects on animals.

This is effected by means of a sampling cylinder, holding about half a cubic foot of gas. In this case, the question of a slight contamination by air, or the fact that the sample is collected over a comparatively long interval of time, is not of much moment, and it is possible to employ the arrangement, consisting of a piston actuated by a falling weight, shown in figs. 65 and 66.

This sampler, like the one previously described, is put into operation by the explosion itself completing an electric circuit by means of a contact maker. The

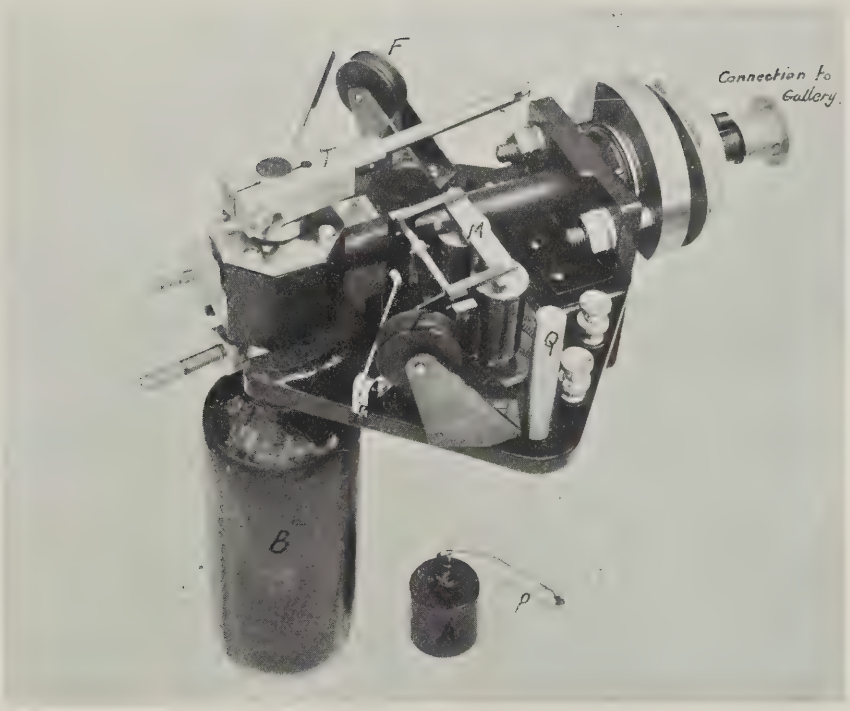



Fig. 62.—The B.C.D. Sampling Bottle. For obtaining samples of afterdamp.

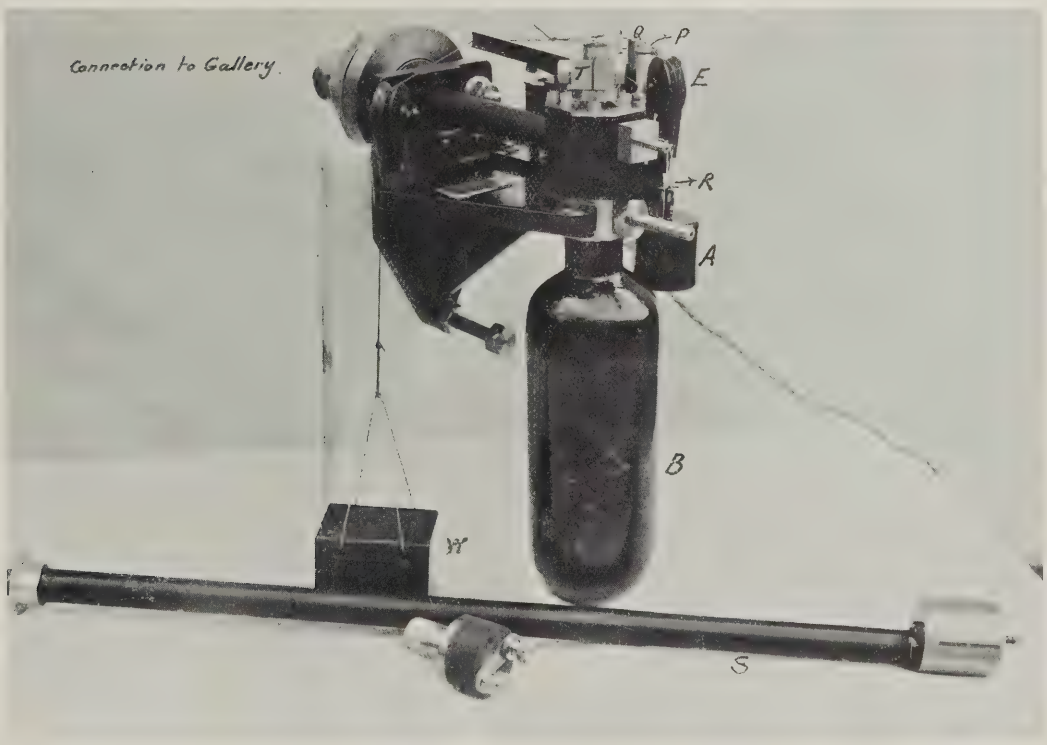



Fig. 63.—The B.C.D. Sampling Bottle. Showing Connecting Pipe.

Fig. 65.—The B.C.D. Sampling Cylinder. Before firing.

Fig. 66.—The B.C.D. Sampling Cylinder. After firing.

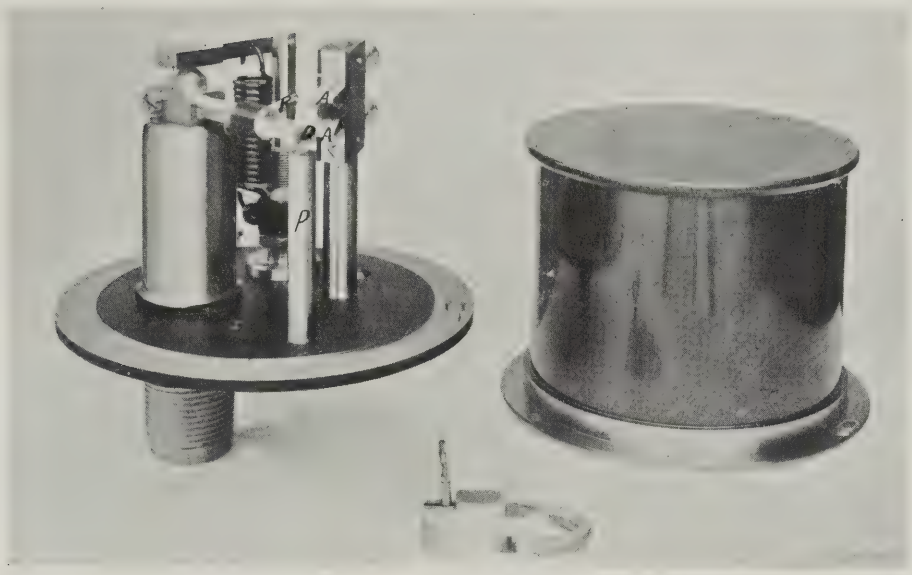



Fig. 67.—Moving Piston Contact Maker. Before firing.

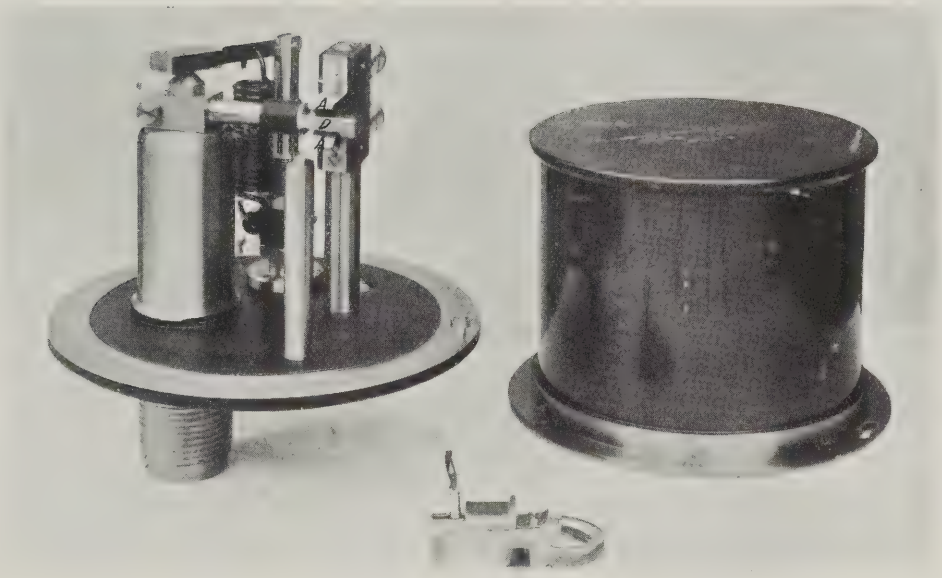



Fig. 68.—Moving Piston Contact Maker. After firing.

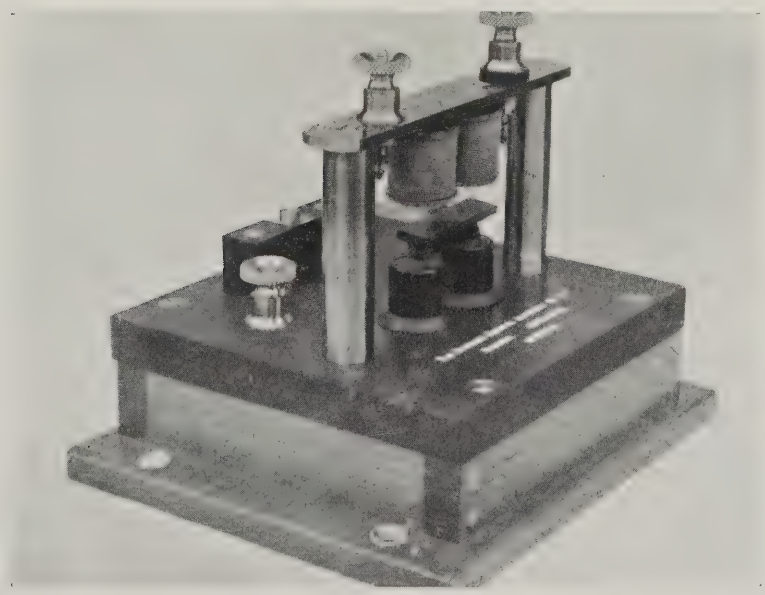


Fig. 69.—Mercury Cup Contact Maker.

completion of the circuit fuses a wire, thereby allowing a heavy weight W, attached by a cord to the head of the piston, to fall. When the piston has completed its stroke, and in so doing has drawn a sample of afterdamp into the cylinder, a catch is released, which causes a valve to close and retain the sample. After the explosion this sample can be forced out into a box containing the mice or birds on which it is desired to experiment.

Fig. 65 shows the cylinder ready for an experiment, and fig. 66 its position after action.

### The B.C.D. Contact Makers.

An arrangement for enabling the explosion itself to complete an electric circuit, and thereby put the sampling apparatus into operation, is of great value, since it ensures that the sample shall be taken at a known time. Thus, if the contact maker is placed at a distance of 200 ft., and the sampler at 100 ft., from the point of ignition, it will be known that a certain interval of time has elapsed after the passing of the explosion before the sample is taken. For, supposing the explosion to be travelling at the rate of 1,000 ft. per second between the sampler and the contact maker, $\frac{1}{10}$ second will elapse, since the two are 100 ft. apart. Similarly, the contact maker can be placed in such a position on the gallery as to cause the sampler to act just before the explosion reaches it, so that the extent to which distillation of the coal in a coal dust explosion takes place (if at all) in front of the explosion can be determined.

(*a.*) *The Moving Piston Contact Maker* (figs. 67 and 68).—This instrument only differs from the moving piston circuit breaker already described, in closing an electric circuit instead of breaking one. The contact is made by the pin D being drawn in between the jaws A, A by the pull of a horizontal spring R. In fig. 67 it will be seen that the rod P holds the pin so that the spring cannot pull it between the jaws, but as soon as the explosion forces up the piston the pin is released from the catch at the top of the rod, and the spring is free to pull it into the contact position.

The manner of adjusting the force required to move the plunger is the same as in the case of the circuit breaker.

Fig. 67 shows the instrument before contact is made, and fig. 68 after.

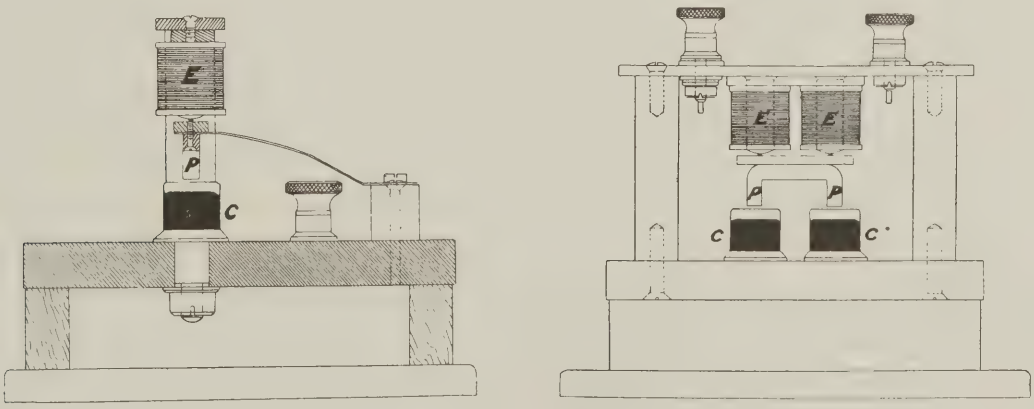



Fig. 70.—Mercury Cup Contact Maker.

(*b.*) *The Mercury Cup Contact Maker* (figs. 69 and 70).—In the case of a weak explosion which may not exercise sufficient pressure to move the plunger of the moving piston contact maker, it is necessary to have an arrangement which will

be actuated by the flame of the explosion. This is effected by the mercury cup contact maker.

An electric current of low voltage passes through the electro-magnet E (fig. 70) of the contact maker, which is connected in series with a narrow strip of tinfoil in the gallery (one of the tinfoil contact breakers used for determining the velocity of the explosion is employed). So long as the current is passing, the armature of the magnet is held up, suspending two projections P, P, one at each end, above two cups C, C containing mercury.

When the flame in the gallery destroys the tinfoil, the circuit through the magnet is broken and the armature falls (fig. 69), thus bridging across the mercury cups and completing a 100-volt circuit to the sampler.

## THE MEASUREMENT OF TEMPERATURE.

The fact that the rate at which combustion proceeds during the course of a coal dust explosion is very rapid, means that the quantity of heat disengaged in any given time interval must be very great, so that the products of combustion will attain a very high temperature.

Assuming for the sake of simplicity that it is required to make a direct determination of the temperature reached by the products of combustion when the oxygen in 1 cubic foot of air burns the quantity of pure carbon necessary for complete combustion to form carbon dioxide, it can be calculated that the quantity of heat disengaged in about 102 B.T.U., and the temperature to which this quantity of heat can raise the products of combustion is about 6,350 degs. Fahr.

Of the methods of thermal measurement that have been devised, one only appears to be capable of giving any approximation of such a high temperature under the conditions that exist in a coal dust explosion.

It is a well-known physical law that the resistance afforded by pure metals to the passage of an electric current increases as their temperature is raised. Since the measurement of electrical resistance is capable of great accuracy, an indirect determination of temperature can thus be obtained by placing in the source of heat a wire through which a small electric current is passing and measuring the change in resistance that takes place. The metal usually chosen for the "thermometer" is pure platinum, on account of its high melting point and its resistance to chemical change. The melting point of pure platinum is about 3,230 degs. Fahr., so that should a thermometer made of this metal be subjected for any length of time to a temperature greater than this, it would be destroyed.

In the case of coal dust explosions the total length of duration of high temperature will not be long, while the *maximum* temperature will only be sustained momentarily by reason of the rapid loss of heat by radiation and conduction. This makes it necessary that the thermometer employed to measure such fugitive temperatures must have a very small heat capacity; that is to say, its weight must be reduced to a minimum. The difficulty then has to be faced of constructing the thermometer strong enough to resist the high pressure that is developed. A thin wire is obviously too fragile, but by depositing platinum as a film upon a plate of silica, strength and delicacy can be combined.

The changes in the electrical resistance of the platinum film which serve to indicate the changes of temperature occurring during the explosion can be recorded by means of a dead-beat galvanometer.

Though direct measurement can be attempted in this manner, calculations made from the records of pressure give a value probably nearer the truth.

Since the instruments that have been devised for the British coal dust experiments for measuring temperature have not yet been sufficiently tested, the Committee consider it advisable to defer the description of them to a future report.

## CHAPTER VI.

# EXPERIMENTS WITH DUSTLESS AND STONE DUST ZONES.

CHAPTER VI.

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# EXPERIMENTS WITH DUSTLESS AND STONE DUST ZONES.

As has already been stated, it was decided early in the course of this enquiry to test the effect of stone dust in regard to coal dust explosions.

There were two lines upon which experiments could be conducted—either (1) with a view to limiting the extent of an explosion that had already travelled some distance, or (2) attempts could be made to prevent the primary ignition of coal dust.

Stone dust appears to be applicable to both these methods and, as will be seen from the results here recorded, the experiments have proved very encouraging.

## I.—THE CHECKING OF AN EXPLOSION AFTER IT HAS TRAVELLED SOME DISTANCE.

It was known that in the Altofts Explosion of 1886 the flame of the explosion, which had traversed the main haulage roads upon which coal dust had accumulated, was unable to penetrate far along the stone dust roads. It appeared, therefore, that valuable information could be obtained regarding the manner in which stone dust acted by reproducing artificially the conditions which were known to have existed in the mine at the time of the Altofts Explosion. That is to say, a coal dust explosion should be caused to travel a certain distance and then be faced by a length of roadway strewn with stone dust. The distance that the flame would penetrate into this stone dust "zone," compared with the distance that it would travel when no stone dust was present, would then decide the value of such a zone.

The first trial that was made in this manner was carried out on July 18th, 1908 (Experiment No. 22).

This experiment warranted a continuance of the trial of stone dust. It was not, however, considered advisable to publish details regarding the use of stone dust until instruments had been procured capable of giving accurate pressure and velocity records; for otherwise the results would be of an empirical nature, depending mainly upon personal observation. The preliminary trials that were made before the instruments had been obtained showed that the normal flame of the explosion might be reduced by the presence of a stone dust zone in its path, but they gave no indication of any reduction in the force developed. To many, indeed, who witnessed the trials, the force appeared to be greater. That such is not the case, but that the pressure produced is materially decreased as soon as the explosion reaches the stone dust zone, is substantially proved by later experiments, the records of some of which are reproduced here.

## Experiments with Stone Dust Zones.

The effects of a stone dust zone placed in the path of a coal dust explosion must be compared with the phenomena arising from an explosion travelling over the same length of coal dust placed in the same relative position in the Experimental Gallery. That is to say, they must not be compared (as regards length of flame, &c.), with the phenomena of an explosion of the same length of coal dust ending at the downcast, for in the latter case the flame is projected out into the open air, and a more rapid release of pressure occurs.

If, however, the coal dust zone of a standard length be placed so that it occupies the same relative position in the gallery in all tests, a more accurate comparison can be made. Thus, if a stone dust zone of 150 ft. placed in front of a coal dust zone of 275 ft. is being tested, it must be compared with an explosion from a similar length of coal dust with 150 ft. of gallery free from dust in front of it. In this manner it can better be judged whether the stone dust has any specific effect in reducing the distance to which excess of coal dust can be driven in advance of the explosion proper. Such excess of coal dust—the "pioneering cloud"—is always swept up in front of the explosion, and has the effect of prolonging the distance through which flame can be propagated over a roadway previously free from dust.

*Experiments Nos. 55 and 57.*—In Experiments Nos. 55 and 57, comparison has been made in the prescribed manner, and the following records have been obtained :—

1. The length of flame.
2. The pressure developed at the end of a coal dust zone of 275 ft. (pressure record B).
3. The pressure developed at a point 100 ft. nearer the downcast. (pressure record A).

In Experiment No. 55, the pressure record A shows the pressure that existed at the end of a previously dustless zone of 100 ft. ; while in Experiment No. 57 the same manometer records the pressure at the end of a stone dust zone of the same length.

The results show that the presence of a cloud of stone dust in the air immediately in front of an explosion from 275 ft. of coal dust prevents the flame being propagated through so great a distance as when no such stone dust zone exists.

In Experiment No. 55, without stone dust, the flame of the explosion from the 275 ft. of coal dust, fed by the excess of dust whirled in advance, extended the whole length of the previously dustless zone, 150 ft., and shot out 16 ft. beyond the downcast end into the air.

In Experiment No. 57, with stone dust, the flame travelled only 55 ft. into the stone dust zone.

The pressure records afford corroborative proof (Plates VII. and VIII.). It will be seen from the inset diagram accompanying each record, that curve B in each experiment shows the pressure developed after the explosion had traversed 275 ft. of coal dust road ; so that, if the conditions of the experiment (such as fineness of dust, amount of dust in suspension, &c.) were similar in each case, the two curves should be approximately identical.

Examination of the curves will show that such is the case, their agreement being very close, both as regards the maximum pressure recorded and the rate of development of that pressure.

Curve A, on the other hand, is obtained from a manometer fixed 100 ft. further on towards the downcast, and therefore should show whether any further propagation of the explosion has taken place between manometer B and that point. If stone dust has a material influence in checking the propagation of explosion, no further increase in pressure should be observed at manometer A in Experiment No. 57 ; whilst if in the absence of stone dust the explosion continues to be propagated, manometer A should show a higher pressure than manometer B in Experiment No. 55.

The records obtained amply bear out these expectations and establish the value of stone dust under the circumstances of the experiment. A coaldust explosion that develops a maximum pressure of 40 lb. per square inch is shown to have been checked in Experiment No. 57, since the pressure recorded at manometer A is less by about 10 lb. per square inch ; an explosion developing practically the same force is shown to have increased in violence when no stone dust was present, a maximum pressure of 100 lb. per square inch being recorded by manometer A in Experiment No. 55.

*Experiments Nos.* 58 *and* 62.—In this pair of experiments the same means of testing the value of a stone dust zone were employed as in Experiments Nos. 55 and 57, just described, the coal dust explosions being developed in the same relative positions in the gallery. The stone dust zone (Experiment No. 58), which was placed in the path of the explosion, was, however, only 100 ft. in length and was succeeded by a length of 50 ft. of coal dust zone, with the object of seeing whether the flame of the explosion would leap the stone dust zone and ignite the coal dust beyond it.

In order to obtain similar conditions in the comparative experiment without stone dust (No. 62), a zone of 50 ft. of coal dust was placed beyond the dustless zone of 100 ft., although it was realised from previous experiments that the flame of the explosion would leap the 100 ft.

In Experiment No. 58, the flame from the explosion of 275 ft. of coal dust extended a distance of 54 ft. only into the stone dust zone ; whereas in Experiment No. 62 the flame travelled the whole length of the previously dustless zone (100 ft.) and ignited the second coal dust zone of 50 ft. beyond, a length of flame of 100 ft. being projected out into the air at the downcast end.

The pressure curves (Plates IX. and X.) are similar in character to those of Experiments Nos. 55 and 57. The maximum pressure due to the coal dust explosion of 275 ft. was in Experiment No. 58, 30·5 lb. per square inch, and in Experiment No. 62, 39·5 lb. per square inch, as recorded by manometer B. But whereas in Experiment No. 62 a maximum pressure of 84 lb. per square inch was attained after a further 100 ft. of travel, in Experiment No. 58, with stone dust, the maximum pressure was reduced to 17·5 lb. per square inch.

*Experiment No.* 116.—The experiments just described deal only with the confining of an explosion travelling towards the downcast and against the normal direction of the air current, but several experiments have been made in which a coal dust zone has been sandwiched between stone dust zones, and ignition has been effected in such a manner as to cause the explosion to travel in both directions.

Experiment No. 116 is a good example of the kind of result obtained.

The position and extent of the coal dust and stone dust zones *in front of* the point of ignition were the same in this experiment as in No. 58, and the effects produced by the explosion travelling towards the downcast in these two experiments can therefore be compared. On the return side, however, starting from the point of ignition, there was a length of 100 ft. of coal dust followed by a stone dust zone reaching to the junction, a further distance of 75 ft.

The result is shown diagrammatically in the inset diagram on Plate XI. The flame penetrated 22 ft. into the stone dust zone towards the downcast, and 46 ft. towards the return. In the latter direction, when no stone dust is present, the flame of the explosion is usually carried along the return, distances varying from 100 ft. to 200 ft., and in some cases as far as the fan, the distance depending largely upon the quantity of dust that has been carried by the ventilating current towards the fan previous to ignition. That the flame should have penetrated no further than 46 ft. in this direction when stone dust was present is significant.

The pressure curves (Plate XI.) show similar characteristics to those obtained in Experiment No. 58 ; the maximum pressure developed by the coal dust explosion after travelling 275 ft. towards the downcast (curve B) was 33·8 lb. per square inch ; while 100 ft. further on, at the end of the stone dust zone, the maximum pressure had fallen to 9·5 lb. per square inch.

### Dustless Zones.

As regards the value of a *dustless* zone in actual practice, these experiments do not afford a complete answer.

It seems natural to suppose that, although the explosion carries in front of it a cloud of unburnt coal dust which enables it to bridge over a length of 150 ft. of previously dustless road, this would not be continued indefinitely, and that, in all probability, a sufficient length of road kept scrupulously clear of coal dust would ultimately cause the explosion to die out for lack of fuel. The use of a dustless zone as a remedy cannot be recommended, however, for reasons which will appear in the ensuing pages.

## EXPERIMENTS WITH STONE DUST ZONES.

*Note.*—In the diagrams illustrating the following experiments, the distance that the flame travelled towards the return has been recorded for the sake of completeness. All comparisons between the experiments must, however, be concerned solely with the development of the explosion towards the downcast. (*See* page 14).

# EXPERIMENT No. 55.

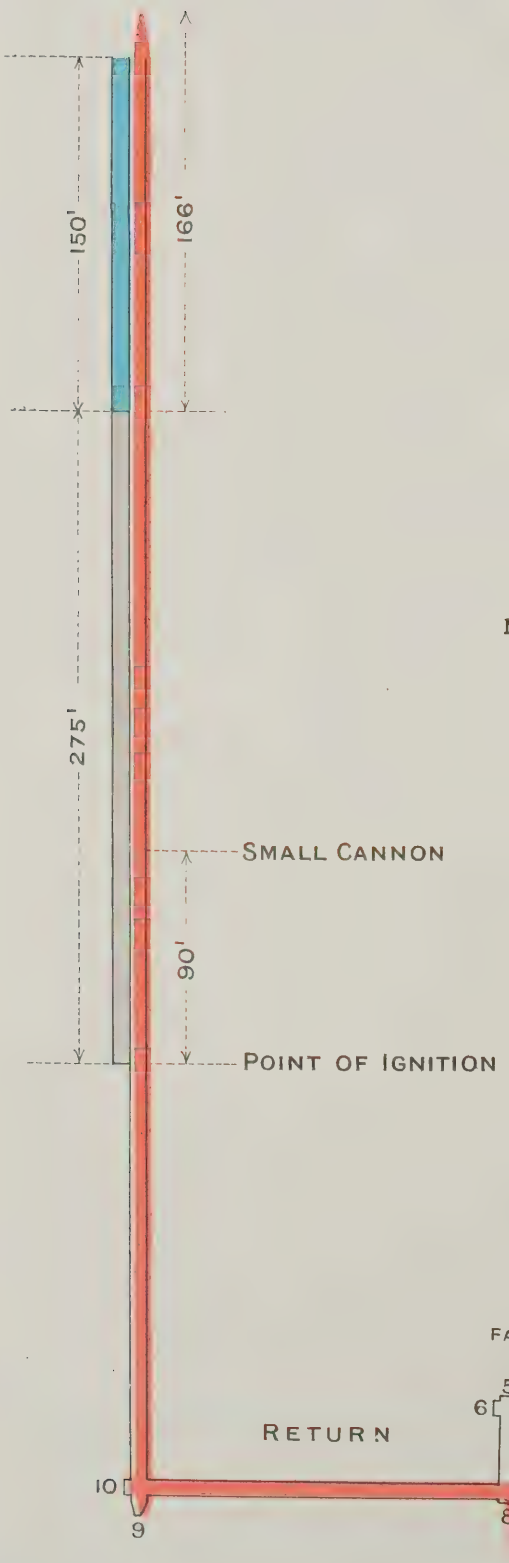
JULY 2ND, 1909.

| | |
|---|---|
| LENGTH OF INTAKE ... ... ... | 600 ft. |
| SECTIONAL AREA OF INTAKE ... | 41 sq. ft. |
| LENGTH OF RETURN... ... ... | 295 ft. |
| SECTIONAL AREA OF RETURN ... | 28 sq. ft. |

COAL DUST ZONE, 275 FT., THUS ...

DUSTLESS ZONE, 150 FT., THUS ...

FLAME ... ... ... ... ...




## PLAN.

SCALE: $\frac{1}{960}$ or 80 ft. equals One Inch.

## METEOROLOGICAL CONDITIONS.

| | |
|---|---|
| Barometer ... .. ... ... | 30·02 in. |
| Thermometer, External ... ... | 71° Fahr. |
| ,, Internal ... ... | 82° ,, |
| Humidity, External ... ... ... | 47 % |
| ,, Internal ... ... ... | 57 % |
| Direction of Wind ... ... ... | S.S.E. |
| General State of Weather ... ... (at time of Experiment) | Fine, 1·20 p.m. |

***NOTE.—Relief valves shown by numbers 1, 2, 3, etc.***

## EXPERIMENT No. 55.

### Main Object of Experiment.

Experiment for comparison with No. 57.

### Special Conditions.

The "standard length" of coal dust zone (275 ft.) moved 150 ft. towards the return so as to occupy the same relative position as in the stone dust experiment with which comparison is made (No. 57).

Position of igniter, 425 ft. from downcast.

Quantity of air, 60,000 cubic feet per minute.

Velocity of air, 1,450 ft. per minute.

Quantity of coal dust, 1 lb. per linear foot = 0·4 oz. per cubic foot.

Large cannon, charge 24 oz. ; clay stemming, 8 in.

Small cannon, charge 4 oz. ; clay stemming, 4 in.

Number of sets of timber in main intake, set every 9 ft. from the downcast to the point of ignition.

### Name and Particulars of Coal Used.

Seam, Silkstone.

Colliery, Messrs. Pope and Pearson, Altofts.

### Analysis.

| | Per cent. |
|---|---|
| Moisture | 2·47 |
| Volatile matter | 33·40 of dry coal |
| Fixed carbon | 62·04 ,, ,, |
| Ash | 4·56 ,, ,, |

### Fineness.

| | Per cent. |
|---|---|
| Remaining on 100 mesh | 4·5 |
| Through 100 on 150 ,, | 9·5 |
| ,, 150 on 200 ,, | 3·5 |
| ,, 200 on 240 ,, | 7·0 |
| ,, 240 and finer | 75·5 |

### Result.

The flame shot out 16 ft. from the downcast end, being a total of 166 ft. beyond the coal dust zone.

All props were blown down.

A tub placed 6 ft. inside from the downcast was hurled 600 ft.

Valve No. 10 was blown out, the timber composing it being thrown 182 ft.

Maximum pressure recorded on manometer B = 40 lb. per square inch.

Maximum pressure recorded on manometer A = 100 lb. per square inch.

(*See* pressure curves, Plate VII.)

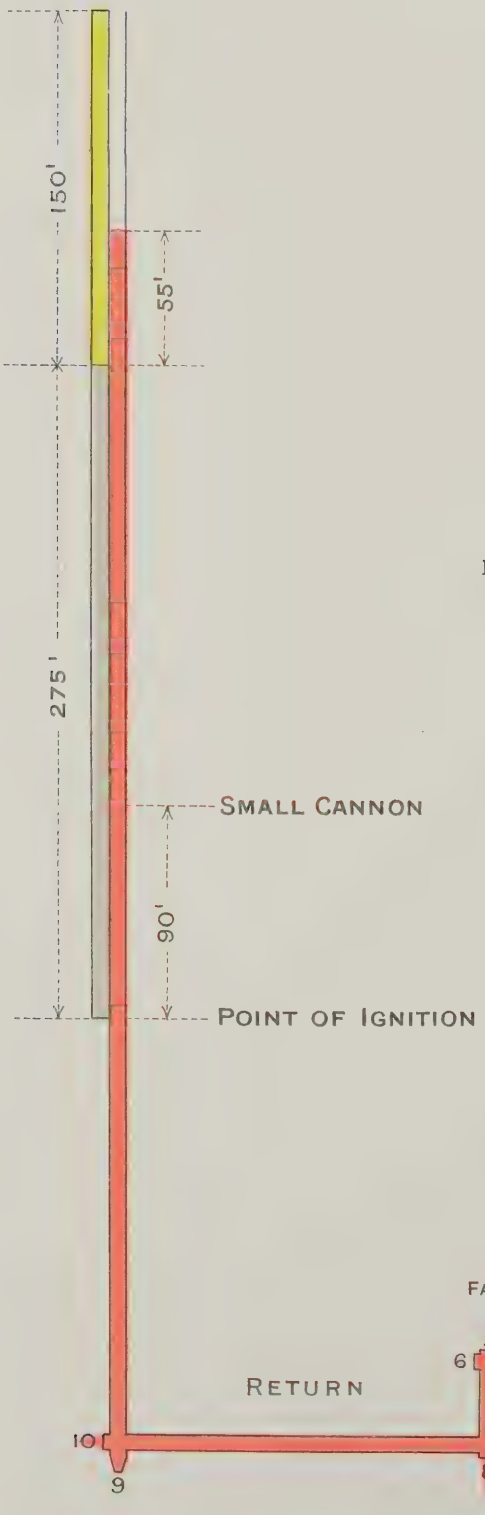
# EXPERIMENT No. 57. JULY 8TH, 1909.

| | |
|---|---|
| LENGTH OF INTAKE ... ... ... | 600 ft. |
| SECTIONAL AREA OF INTAKE ... | 41 sq. ft. |
| LENGTH OF RETURN... ... ... | 295 ft. |
| SECTIONAL AREA OF RETURN ... | 28 sq. ft. |

COAL DUST ZONE, 275 FT., THUS...

STONE DUST ZONE, 150 FT., THUS...

FLAME ... ... ... ... ...




## PLAN.

SCALE : $\frac{1}{960}$ or 80 ft. equals One Inch.

## METEOROLOGICAL CONDITIONS.

| | |
|---|---|
| Barometer ... .. ... ... | 29·6 in. |
| Thermometer, External ... ... | 71° Fahr. |
| ,, Internal ... ... | 83° ,, |
| Humidity, External ... ... ... | 53 % |
| ,, Internal ... ... ... | 64 % |
| Direction of Wind ... ... ... | South. |
| General State of Weather ... (at time of Experiment) ... | Fine and Warm, 1·30 p.m. |

***NOTE.—Relief valves shown by numbers 1, 2, 3, etc.***

## EXPERIMENT No. 57.

### Main Object of Experiment.

To test the value of a stone dust zone placed in the path of a coal dust explosion.

### Special Conditions.

A zone of stone dust, 150 ft. in length, starting from the downcast, was placed in front of a coal dust zone of 275 ft. The stone dust was spread at the rate of 15 lb. per linear foot upon brattice cloth placed near the roof and upon shelves along the gallery.

Position of igniter, 425 ft. from downcast.

Quantity of air, 60,000 cubic feet per minute.

Velocity of air, 1,450 ft. per minute.

Quantity of coal dust, 1 lb. per linear foot = 0·4 oz. per cubic foot.

Large cannon, charge, 24 oz. ; clay stemming, 8 in.

Small cannon, charge, 4 oz ; clay stemming, 4 in.

Number of sets of timber in main intake, set every 9 ft. from downcast to point of ignition.

### Name and Particulars of Coal Used.

Seam, Silkstone.

Colliery, Messrs. Pope and Pearson, Altofts.

| Analysis. | Per cent. | Fineness. | Per cent. |
|---|---|---|---|
| Moisture | 2·81 | Remaining on 100 mesh | 4·0 |
| | | Through 100 on 150 ,, | 7·5 |
| Volatile matter | 33·52 of dry coal | ,, 150 on 200 ,, | 5·0 |
| Fixed carbon | 62·76 ,, ,, | ,, 200 on 240 ,, | 10·0 |
| Ash | 3·72 ,, ,, | ,, 240 and finer | 73·5 |

### Result.

The explosion sounded very violent.

Tub blown out of downcast 372 ft.

Valve No. 10 blown out 180 ft.

No flame issued from the downcast, and on examination of tufts of cotton wool and guncotton placed every few feet along the sides of the gallery it was found that the flame had only penetrated 55 ft. into the stone dust zone.

Maximum pressure recorded at manometer B = 40 lb. per square inch.

Maximum pressure recorded at manometer A = 9 lb. per square inch.

(*See* pressure curves, Plate VIII.)

# EXPERIMENT No. 58.

JULY 10TH, 1909.

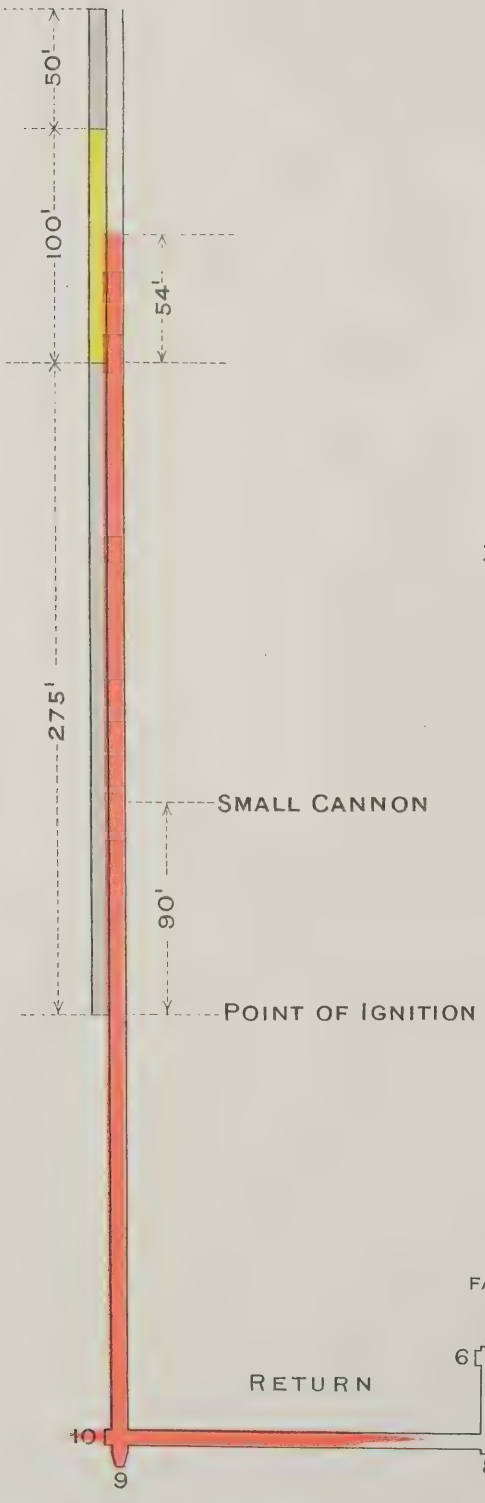
| | |
|---|---|
| LENGTH OF INTAKE ... ... ... | 600 ft. |
| SECTIONAL AREA OF INTAKE ... | 41 sq. ft. |
| LENGTH OF RETURN... ... ... | 295 ft. |
| SECTIONAL AREA OF RETURN ... | 28 sq. ft. |

COAL DUST ZONE, 275 FT., THUS...

COAL DUST ZONE, 50 FT., THUS...

STONE DUST ZONE, 100 FT., THUS...

FLAME ... ... ... ... ...




## PLAN.

SCALE : $\frac{1}{960}$ or 80 ft. equals One Inch.

## METEOROLOGICAL CONDITIONS.

| | |
|---|---|
| Barometer ... .. ... ... | 29·6 in. |
| Thermometer, External ... ... | 60·54° Fahr. |
| ,, Internal ... ... | 68·60° ,, |
| Humidity, External ... ... ... | 66 % |
| ,, Internal ... ... ... | 64 % |
| Direction of Wind ... ... ... | North. |
| General State of Weather ... ... (at time of Experiment) | Raining, 12·45 p.m. |

***NOTE.—Relief valves shown by numbers 1, 2, 3, etc.***

## EXPERIMENT No. 58.

### Main Object of Experiment.

To test the value of a stone dust zone placed in the path of a coal dust explosion.

### Special Conditions.

A stone dust zone of 100 ft. sandwiched between two coal dust zones, one of 275 ft. and the other of 50 ft. Ignition was effected at the return end of the former, while the latter ended at the downcast. The stone dust was distributed as in Experiment 57.

Position of igniter, 425 ft. from downcast.

Quantity of air, 60,000 cubic feet per minute.

Velocity of air, 1,450 ft. per minute.

Quantity of coal dust, 1 lb. per linear foot = 0·4 oz. per cubic foot.

Large cannon, charge 24 oz. ; clay stemming, 8 in.

Small cannon, charge 4 oz. ; clay stemming, 4 in.

Number of sets of timber in main intake, set every 9 ft. from downcast to point of ignition.

### Name and Particulars of Coal Used.

Seam, Silkstone.

Colliery, Messrs. Pope and Pearson, Altofts.

**Analysis.**

| | Per cent. |
|---|---|
| Moisture | 2·36 |
| Volatile matter | 33·56 of dry coal |
| Fixed carbon | 62·28 ,, ,, |
| Ash | 4·16 ,, ,, |

**Fineness.**

| | Per cent. |
|---|---|
| Remaining on 100 mesh | 6·00 |
| Through 100 on 150 ,, | 11·00 |
| ,, 150 on 200 ,, | 2·25 |
| ,, 200 on 240 ,, | 9·00 |
| ,, 240 and finer | 71·75 |

### Result.

The flame penetrated only 54 ft. into the stone dust zone.

Tub blown 504 ft. from downcast.

Valve No. 10 blown out 225 ft.

Maximum pressure recorded on manometer B = 31 lb. per square inch.

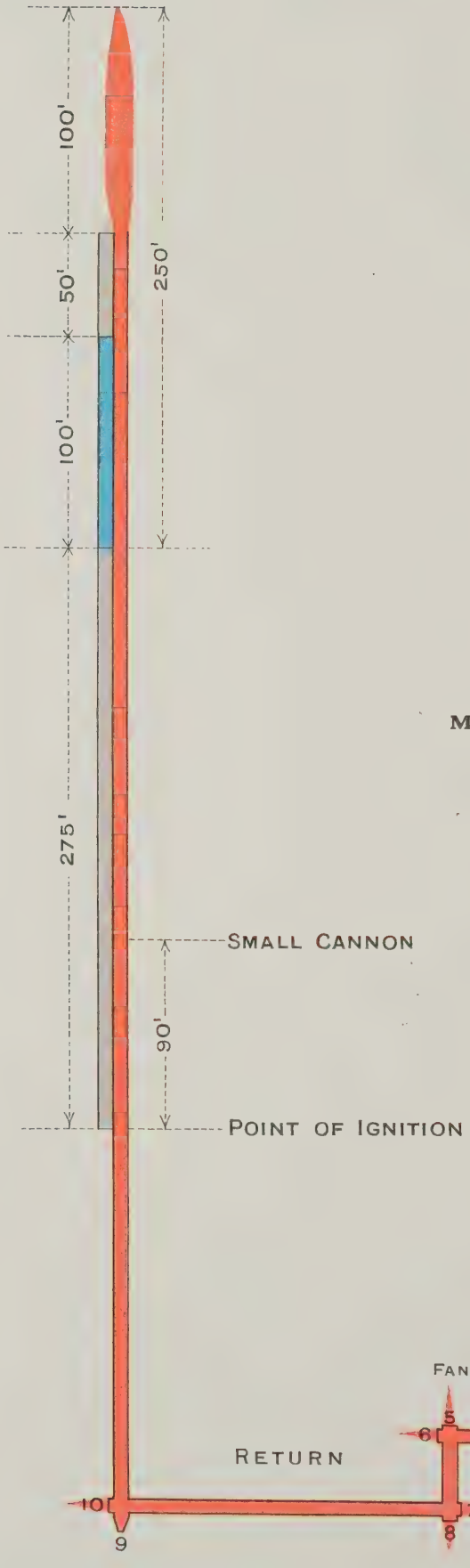
Maximum pressure recorded on manometer A = 17·5 lb. per square inch.

(*See* pressure curves, Plate IX.)

# EXPERIMENT No. 62.

JULY 21st, 1909.

| | |
|---|---|
| Length of Intake ... ... ... | 600 ft. |
| Sectional Area of Intake ... | 41 sq. ft. |
| Length of Return... ... ... | 295 ft. |
| Sectional Area of Return ... | 28 sq. ft. |
| Coal Dust Zone, 275 ft., thus ... | |
| Coal Dust Zone, 50 ft., thus ... | |
| Dustless Zone, 100 ft., thus ... | |
| Flame ... ... ... ... ... | |




## PLAN.

Scale : $\frac{1}{960}$ or 80 ft. equals One Inch.

## METEOROLOGICAL CONDITIONS.

| | |
|---|---|
| Barometer ... .. ... ... | 29·7 in. |
| Thermometer, External ... ... | 63° Fahr. |
| ,, Internal ... ... | 71·6° ,, |
| Humidity, External ... ... ... | 67 % |
| ,, Internal ... ... ... | 69 % |
| Direction of Wind ... ... ... | North. |
| General State of Weather ... ... (at time of Experiment) | Fine, 5·30 p.m. |

***NOTE.—Relief valves shown by numbers 1, 2, 3, etc.***

## EXPERIMENT No. 62.

### Main Object of Experiment.

Experiment for comparison with No. 58.

### Special Conditions.

The "standard length" of coal dust zone (275 ft.) moved 150 ft. towards the return so as to occupy the same relative position as in the stone dust experiment, with which comparison is made (No. 58). The first 50 ft. of intake, starting from the downcast, were also strewn with coal dust.

Position of igniter, 425 ft. from downcast.

Quantity of air, 60,000 cubic feet per minute.

Velocity of air, 1,450 ft. per minute.

Quantity of coal dust, 1 lb. per linear foot = 0·4 oz. per cubic foot.

Large cannon, charge, 24 oz.; clay stemming, 8 in.

Small cannon, charge, 4 oz.; clay stemming, 4 in.

Number of sets of timber in main intake, set every 9 ft. from downcast to point of ignition.

### Name and Particulars of Coal Used.

Seam, Silkstone.

Colliery, Messrs. Pope and Pearson, Altofts.

### Analysis.

| | Per cent. | |
|---|---|---|
| Moisture | 3·22 | |
| Volatile matter | 33·29 | of dry coal |
| Fixed carbon | 62·56 | ,, ,, |
| Ash | 4·15 | ,, ,, |

### Fineness.

| | Per cent. |
|---|---|
| Remaining on 100 mesh | 5·0 |
| Through 100 on 150 ,, | 11·5 |
| ,, 150 on 200 ,, | 2·5 |
| ,, 200 on 240 ,, | 7·5 |
| ,, 240 and finer | 73·5 |

### Result.

Flame issued from the downcast 100 ft.

Tub blown 528 ft. from downcast.

Valve No. 10 blown out.

Maximum pressure recorded on B manometer = 39·5 lb. per square inch.

Maximum pressure recorded on A manometer = 84 lb. per square inch.

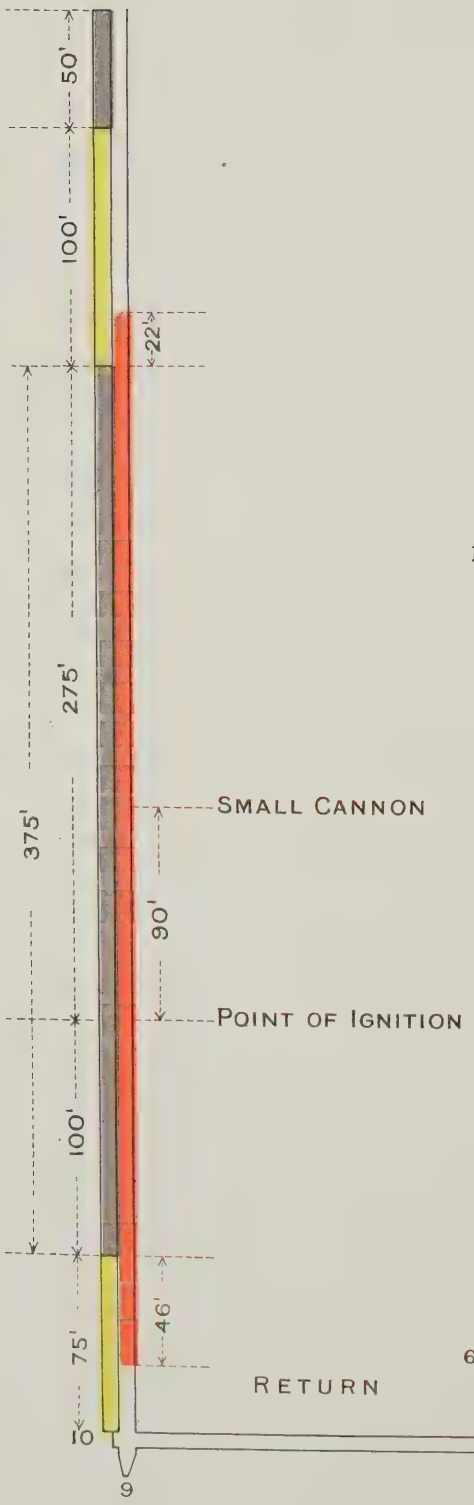
(*See* pressure curves, Plate X.)

# EXPERIMENT No. 116. OCTOBER 22ND, 1909.

| | |
|---|---|
| Length of Intake ... ... ... | 600 ft. |
| Sectional Area of Intake ... | 41 sq. ft. |
| Length of Return... ... ... | 295 ft. |
| Sectional Area of Return ... | 28 sq. ft. |
| Coal Dust Zone, 375 ft., thus... | |
| Coal Dust Zone, 50 ft., thus... | |
| Stone Dust Zone, 100 ft., thus... | |
| Stone Dust Zone, 75 ft., thus... | |
| Flame ... ... ... ... ... | |

## PLAN.

Scale: $\frac{1}{960}$ or 80 ft. equals One Inch.




## METEOROLOGICAL CONDITIONS.

| | |
|---|---|
| Barometer ... .. ... ... | 29·9 in. |
| Thermometer, External ... ... | 58° Fahr. |
| ,, Internal ... ... | 55° ,, |
| Humidity, External ... ... ... | 71 % |
| ,, Internal ... ... ... | 87 % |
| Direction of Wind ... ... ... | South-West. |
| Velocity of Wind ... ... ... | 10 m. per hour. |
| General State of Weather ... ... (at time of Experiment) | Fair, 1·15 p.m. |

***NOTE.—Relief valves shown by numbers 1, 2, 3, etc.***

## EXPERIMENT No. 116.

### Main Object of Experiment.

To test the effect of sandwiching a coal dust explosion between two stone dust zones.

### Special Conditions.

A 375 ft. coal dust zone placed between two stone dust zones, one of 100 ft. (starting 50 ft. from the downcast) and the other 75 ft. (starting from the return) Ignition was effected 175 ft. from return, *i.e.*, 100 ft. into the coal dust zone. The first 50 ft. of the intake strewn with coal dust.

Position of igniter, 425 ft. from downcast.

Quantity of air, 60,000 cubic feet per minute.

Velocity of air, 1,450 ft. per minute.

Quantity of coal dust, 1 lb. per linear foot = 0·4 oz. per cubic foot.

Large cannon, charge, 24 oz. ; clay stemming, 8 in.

Small cannon charge, 4 oz. ; clay stemming, 4 in.

Number of sets of timber in main intake, set every 9 ft. through the whole of the intake.

### Name and Particulars of Coal Used.

Seam, Silkstone.

Colliery, Messrs. Pope and Pearson, Altofts.

#### Analysis.

| | Per cent. |
|---|---|
| Moisture | 3·05 |
| Volatile matter | 33·40 of dry coal |
| Fixed carbon | 62·35 ,, ,, |
| Ash | 4·25 ,, ,, |

#### Fineness.

| | Per cent. |
|---|---|
| Remaining on 100 mesh | 3·50 |
| Through 100 on 150 ,, | 8·50 |
| ,, 150 on 200 ,, | 2·50 |
| ,, 200 on 240 ,, | 7·50 |
| ,, 240 and finer | 78·00 |

### Result.

The flame penetrated 22 ft. into the stone dust zone towards the downcast and 46 ft. into the zone towards the return.

Maximum pressure recorded on B manometer = 33·7 lb. per square inch.

Maximum pressure recorded on A manometer = 9·8 lb. per square inch.

(*See* pressure curves, Plate XI.)

# PLATE VII.

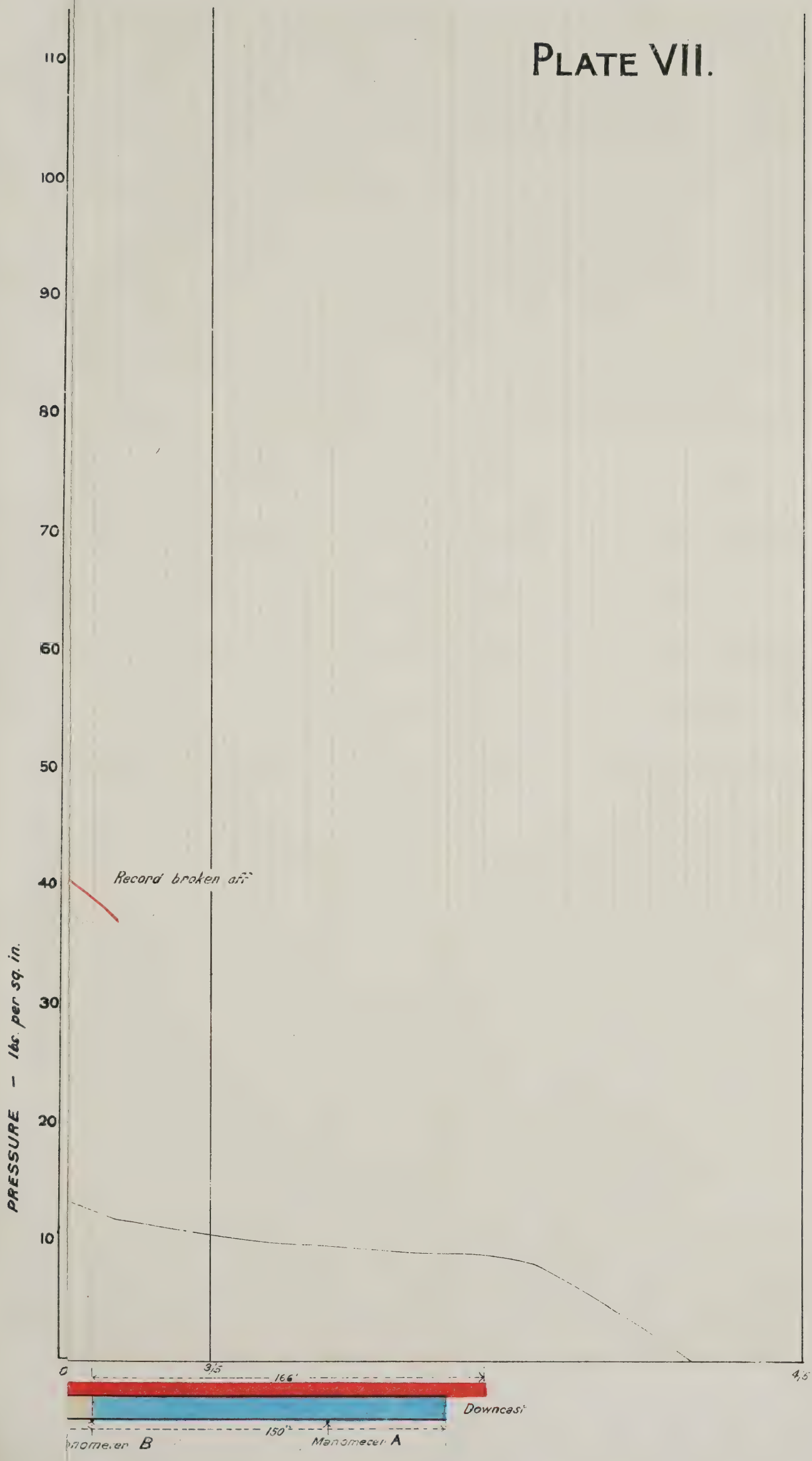
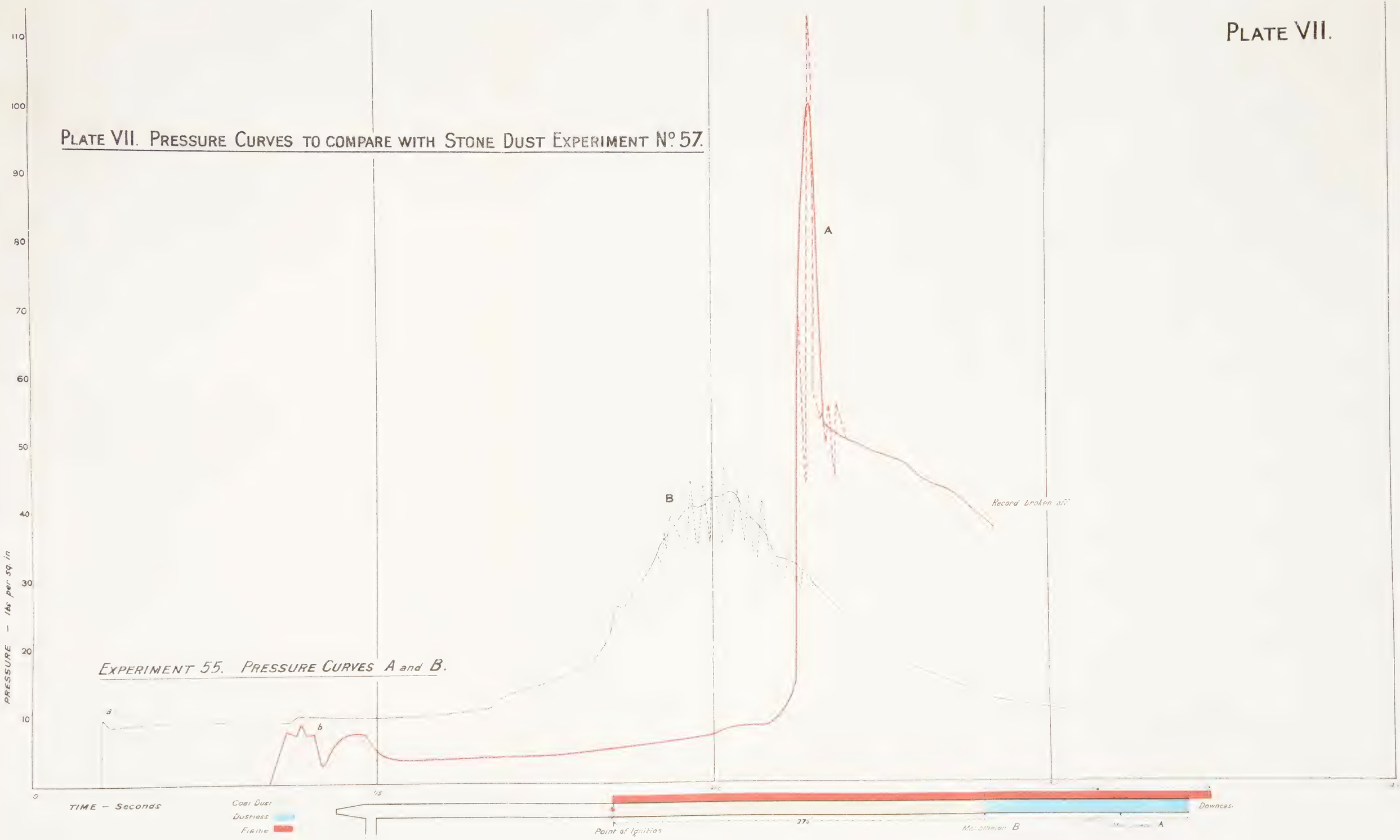
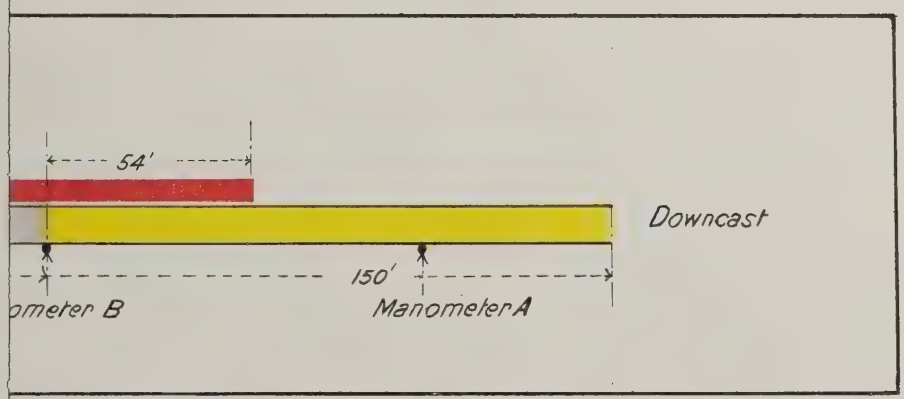

110
100
90
80
70
60
50
40
30
20
10
PRESSURE – lbs. per sq. in.
Record broken off
0
3,15
4,5
166'
150'
Downcast
Manometer B
Manometer A

PLATE VII. PRESSURE CURVES TO COMPARE WITH STONE DUST EXPERIMENT Nº 57.

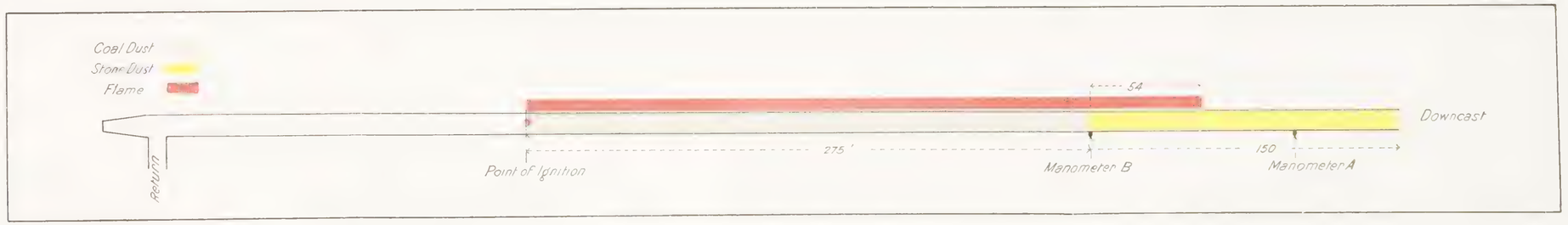


# PLATE VIII.



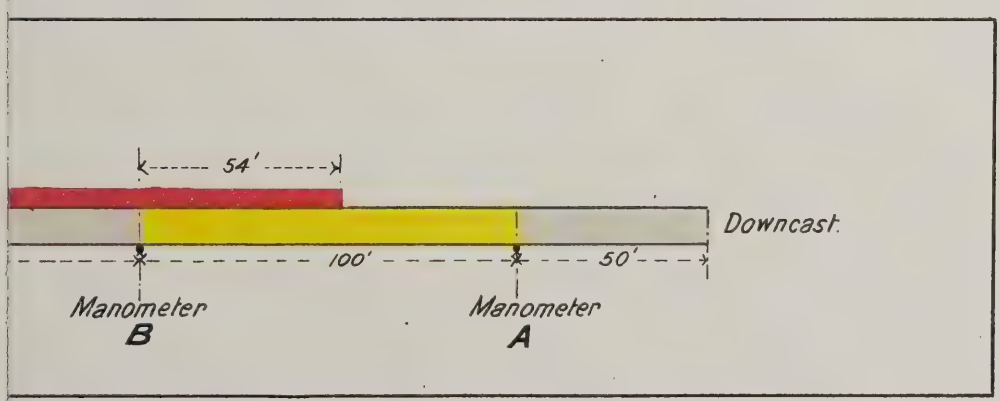

RIMENT. Nº 57.

EXPERIMENT 57. PRESSURE CURVES A and B.



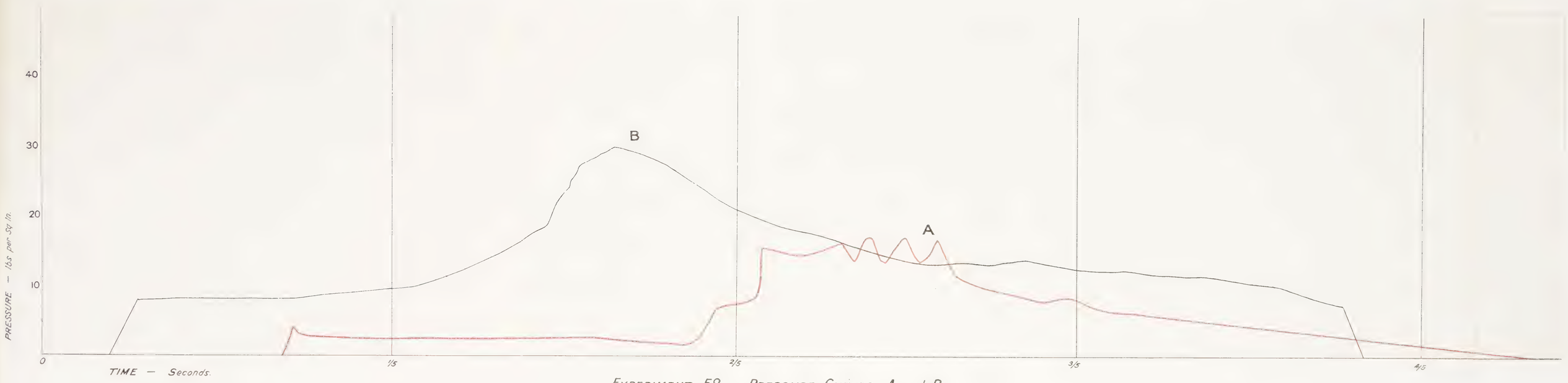

## PLATE VIII. PRESSURE CURVES FROM STONE DUST EXPERIMENT. Nº 57.

# PLATE IX




## EXPERIMENT. No. 58.

# PLATE IX.




EXPERIMENT 58. PRESSURE CURVES, A and B.

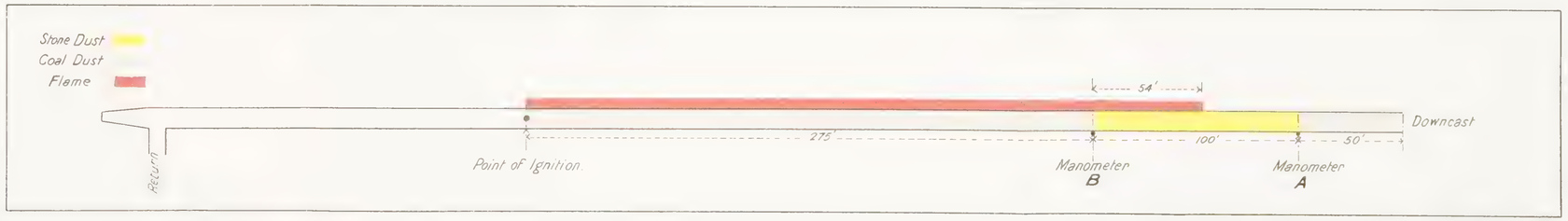



PLATE IX. PRESSURE CURVES FROM STONE DUST EXPERIMENT. Nº 58.

# PLATE X.

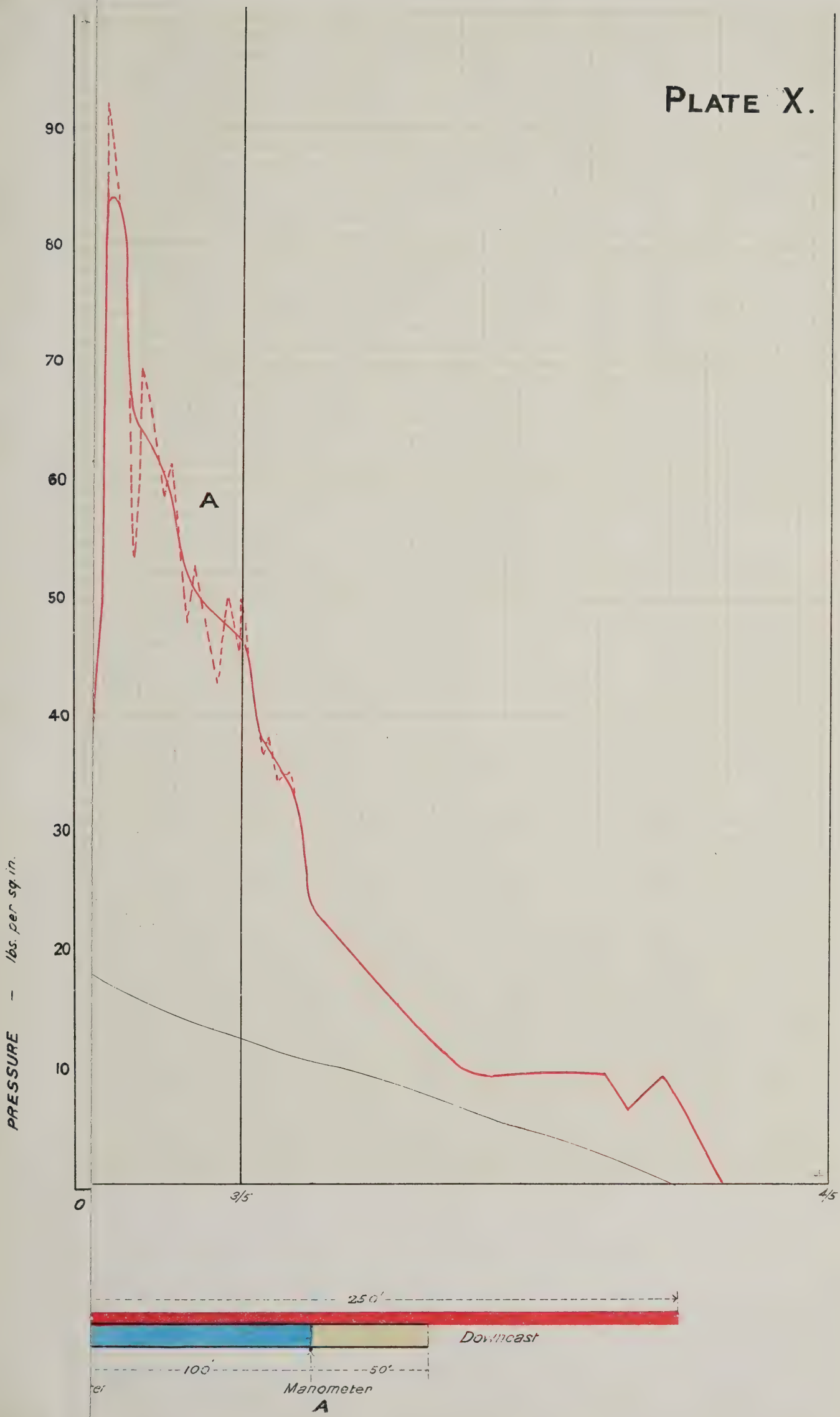
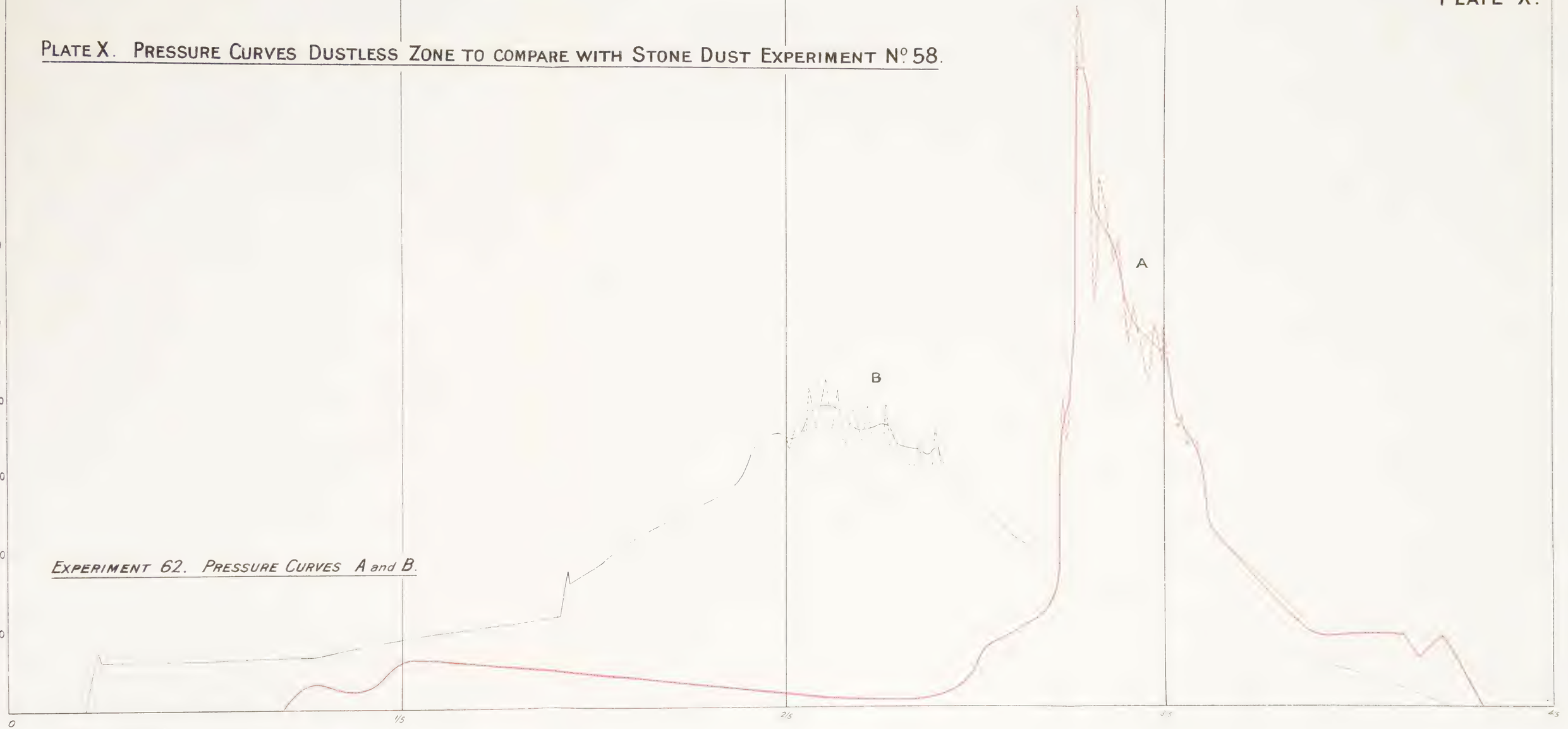
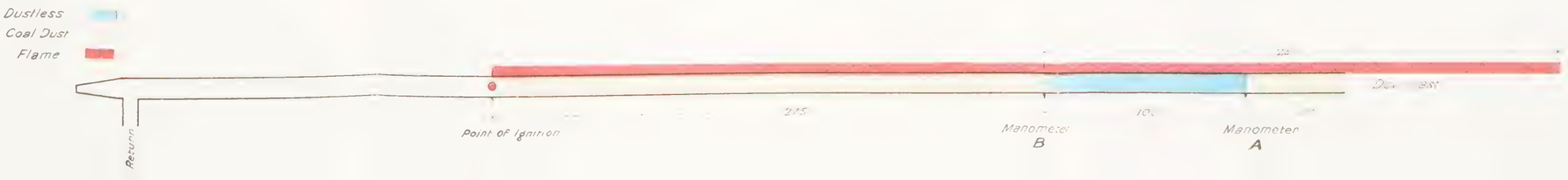

PRESSURE — lbs. per sq. in.
90
80
70
60
50
40
30
20
10
A
0
3/5
4/5
250'
Downcast
100'
50'
Manometer
A

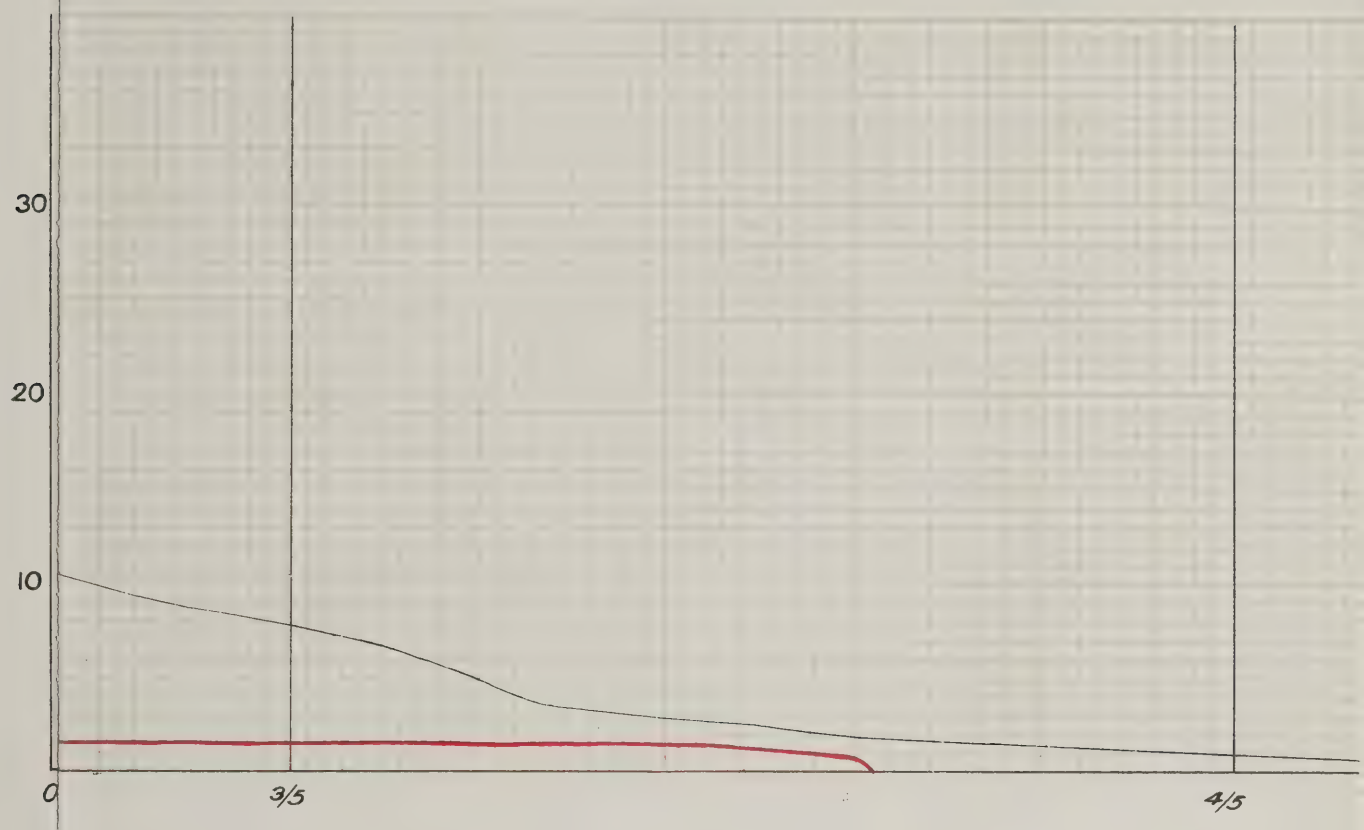
PLATE X. PRESSURE CURVES DUSTLESS ZONE TO COMPARE WITH STONE DUST EXPERIMENT Nº 58.

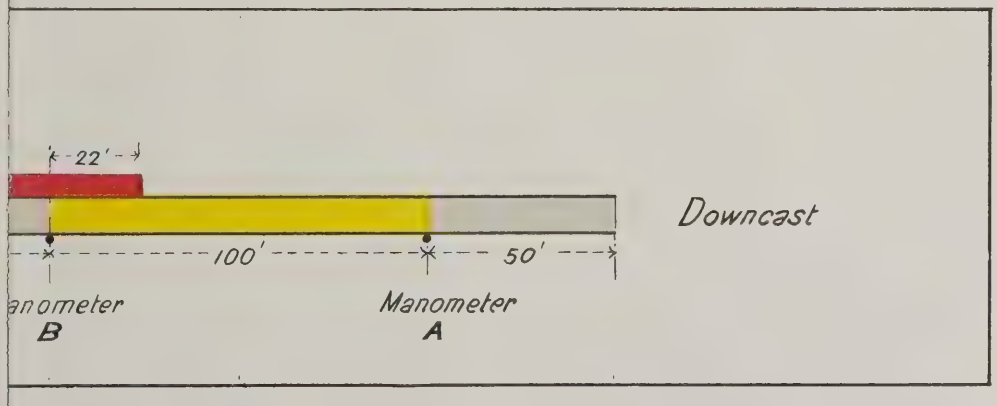
EXPERIMENT 62. PRESSURE CURVES A and B.



# PLATE XI.




RIMENT. Nº 116.

# Plate XI.

Experiment 116. Pressure Curves A and B.

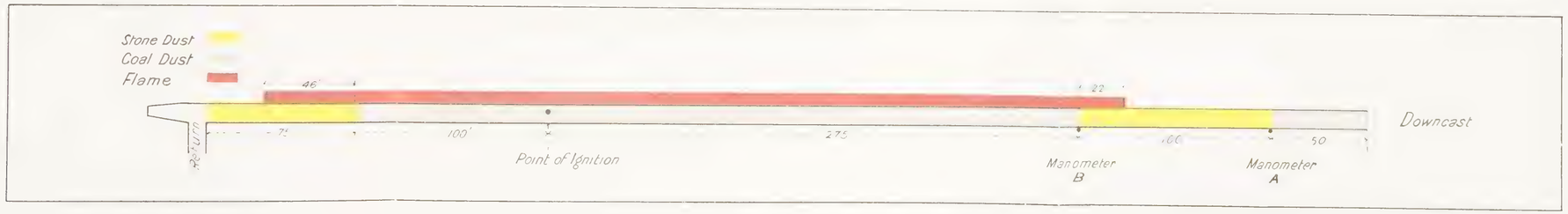



Plate XI. Pressure Curves from Stone Dust Experiment. No. 116.

## II.—THE PREVENTION OF THE PRIMARY IGNITION OF COAL DUST.

General Rule 12 (*h*), Coal Mines Regulation Act, 1887, states that :—"If a "place where a shot is fired is dry and dusty, then the shot shall not be fired unless "one of the following conditions is observed, that is to say :—

"1. Unless the place of firing and all contiguous accessible places within a "radius of 20 yards therefrom are at the time of firing in a wet state through "watering or other treatment equivalent to watering, in all parts where dust is "lodged, whether roof, floor or sides ; or

"2. In the case of places in which watering would injure the roof or floor, "unless the explosive is so used with water *or other contrivance* as to prevent it "from inflaming gas or dust, or is of such a nature that it cannot inflame gas or "dust."*

The main conditions necessary for ignition of coal dust to occur are, (1) the presence of a cloud of combustible dust in a finely divided state, (2) the projection into this cloud of a flame of sufficiently high temperature and volume, and (3) the presence of air. In the experiments here recorded, the dust cloud was assumed to have been raised by the firing of a shot ; the flame to be that arising from a blown-out shot fired a few yards distant from the point where the dust was raised and within a few seconds after its raising ; and the air current to be that ordinarily met with on a main haulage road.

It was imagined that two shots might be fired within 90 ft. of each other and with only a few seconds interval between them. The first shot would do its work but would raise a cloud of dust by the concussion ; the second shot would blow out its tamping without doing any work, and would project an abnormal volume of flame into the dust cloud thus already formed.

*Experiment No.* 63.—The shot which raised the dust was represented by a small cannon of $1\frac{1}{2}$ in. bore charged with 4 oz. of blasting powder with 4 in. of clay stemming, and pointed against the side of the gallery.

The "blown-out shot" was supplied by a cannon of 2 in. bore charged with 24 oz. of blasting powder (with 8 in. of clay stemming), inclined upwards at an angle of 32 degs. with the horizontal and pointed against the air current. Such a charge of powder would give a flame about 12 or 13 feet long.

The air current employed had a velocity of 1,200 ft. per minute, and was sufficient in itself to raise in suspension a considerable quantity of coal dust.

Stone dust was scattered for 60 ft. on either side of each shot, whilst the remainder of the gallery was strewn with coal dust at the rate of 1 lb. per linear foot on shelves, on the floor and on the tops of sets of timber with which the gallery was furnished in resemblance to the roadway of a mine.

The general arrangement is shown on Plate XII.

It will be seen that the air current swept with a high velocity over a length of roadway of 275 ft. strewn with coal dust before it came to the stone dust area. Taking all the factors into consideration, it is apparent that, except for the presence of stone dust, the conditions were in every way favourable to the ignition of the coal dust ; in fact, ignition had been obtained in this manner, when no stone dust was present, in fifty-nine cases out of sixty-two, the exceptions being Nos. 11, 28 and 33, the failure of which was due to known causes.

* The italics do not appear in the original text.

The degree of fineness of the coal dust (pulverised Altofts Silkstone nuts) and of the stone dust (from the strata overlying the Altofts Silkstone seam) was as follows :—

| | Coal dust. | Stone dust. |
|---|---|---|
| | Per cent. | Per cent. |
| Remaining on 100 mesh ..... | 4·0 | 67·5 |
| Through 100 on 150 ,, ..... | 8·0 | 12·0 |
| ,, 150 on 200 ,, ..... | 3·0 | 4·0 |
| ,, 200 on 240 ,, ..... | 7·0 | 3·0 |
| ,, 240 and finer ,, ..... | 78·0 | 13·5 |

The greater coarseness of the stone dust as compared with the coal dust is due to the fact that it was ground in a mortar mill, whilst the latter was pulverised in a disintegrator. It is possible, by a suitable machine, to get the stone dust much finer, in which state it is more effective.

The experiment was carried out under precisely the same conditions as in the case of the demonstrations of the explosive nature of coal dust.* The first shot, which raised the dust, was fired seven seconds after the closing of the fan doors ; the second, representing the blown-out shot, was fired two seconds later.

On firing the shots there was no ignition of coal dust, nor, on examining the interior of the gallery afterwards, was there any evidence of flame on either side of the two cannons.

It has been found that a velocity of air current of 1,200 ft. per minute is sufficient in itself to raise in suspension a considerable quantity of the coal dust, but is incapable of raising the coarser and denser stone dust. In this experiment, therefore, coal dust was gradually carried in suspension into the stone dust area as soon as the fan doors were closed, and partly covered the stone dust with a layer of coal dust. As soon, however, as the small cannon was fired, a cloud of stone dust was raised by it, which, mixing with the coal dust already in suspension, rendered the latter harmless.

*Experiment No.* 59.—This experiment shows that the precaution of distributing stone dust on either side of *each* shot must be rigidly adhered to. In this case the first shot from the small cannon, or "cloud raiser," was fired in a coal dust area, while the blown-out shot occurred in a stone dust zone. The general arrangement is shown on Plate XII.

Explosion occurred and travelled in the direction indicated in the diagram. There was, however, no sign of flame in the opposite direction.

The reason for the explosion in the light of what has been said regarding Experiment No. 63, is readily apparent. The concussion caused by the first shot was sufficient to raise a cloud of the coal dust in its immediate vicinity in addition to that already raised by the air current, but was unable to raise the denser stone dust further away. A cloud of undiluted coal dust was therefore carried right over the blown-out shot which immediately ignited it.

There is one point brought out by this experiment which is of great significance. The concussion produced by the small cannon was insufficient to raise the stone dust in suspension. In mine practice the stone dust would be freshly strewn for 20 yards on either side of each shot : if a blown-out shot is produced, which causes a sudden

* *See* page 14.

concussion insufficient to raise the stone dust in its immediate neighbourhood, it is obvious that neither can the coal dust lying underneath this stone dust be raised in suspension in the air. If, on the other hand, both stone dust and coal dust are raised, other experiments have proved that, within certain limits, the flame produced by a blown-out shot cannot ignite such a cloud of dust if the percentage of incombustible matter present is high (*see* page 106).

This mode of application of stone dust suggests a means of preventing a blown-out shot from igniting coal dust, but it could not guard against any other means of ignition, nor would it be effective in stopping an explosion that has once started. For this latter purpose the more stringent precautions described in the previous pages would seem to be indicated.

## EXPERIMENTS WITH MIXTURES OF COAL DUST AND STONE DUST.

On reflection it will be seen that there are at least three limiting conditions without the simultaneous existence of which a coal dust explosion is unable to take place.

1. The dust must be raised in suspension in the air.
2. A flame of sufficient volume, intensity, and duration must be projected into this dust cloud.
3. A good air supply must be maintained in order that the initial combustion of the dust may not cease for lack of oxygen.

It is assumed as understood that the dust is readily combustible ; that is to say, it must be so finely divided as to allow of its being readily attacked by the oxygen of the air, and that it must not be contaminated with a high percentage of incombustible matter.

It is obvious, therefore, that if any one of these conditions be rendered impossible of occurrence, no explosion can take place, and the problem of prevention of explosion resolves itself into a consideration of which condition can be most readily and infallibly controlled.

1. Taking the first condition, a means of preventing the occurrence of a coal dust explosion lies in rendering the raising of a dust cloud impossible. Several methods have been suggested with this object in view, involving either (*a*) rendering the dust incapable of being raised as a cloud by causing it to cohere together, or (*b*) the complete removal of the dust. Without discussing at length the merits or demerits of the various suggestions that have been put forward for the former purpose, it may safely be said that none of them is *universally* applicable or completely effective. Complete removal of the dust from the mine does not seem to be a practical undertaking, since dust is continually being formed ; while the efficacy of a dustless zone as a means of stopping an explosion that has once started is doubtful. The opinions generally held regarding the value or otherwise of a zone of any description are well shown in the course of evidence given before the present Royal Commission on Mines, Vol. II., 1907.

2. Several mine explosions have been attributed to ignitions of dust at a naked light. Far commoner sources of danger have been the flames produced by blown-out shots, or that resulting from a local ignition of firedamp. The possibility of a naked light, or a defective safety lamp, igniting firedamp cannot be completely eliminated, for the presence of firedamp in some mines is an inevitable consequence

of the process of getting coal, and light is indispensable to the miner at his work. There must, therefore, always be the danger of a local ignition of firedamp being augmented by the presence of coal dust.

3. Ventilation in mines has been gradually increased as occasion demanded for the dispersal of firedamp, and, even if the danger from coal dust were diminished by reducing the velocity of the air current, the risk of explosion from accumulation of firedamp would be increased in proportion.

The impossibility of preventing an explosion taking place by depriving it of the oxygen necessary to propagate combustion is so manifest that it need not be enlarged upon.

It would appear, therefore, that it is impossible to guard against any one of the three conditions necessary for an explosion.

Turning, however, to the question of the dust itself, which it is specified must be of sufficient fineness to remain in suspension in the air, *and must not be contaminated with a high percentage of incombustible matter*, a means of preventing an ignition of coal dust ever occurring would seem to exist in the dilution of the coal dust with dust from some incombustible substance such as stone.

The following series of experiments, details of which are given in Table I., shows the effect of the addition in increasing quantities of incombustible dust to Silkstone coal dust. Each experiment was made with a length of zone of 275 ft., from the downcast to the point of ignition, and this length was set with props and bars every 9 ft. Ignition was effected as usual by the firing of a charge of 24 ounces of blasting powder, tamped with 8 in. of dry clay, pointed towards the downcast. A current of air of 50,000 cubic feet per minute was drawn through the downcast at the time of the explosion.

Great care was taken to ensure uniform mixing of the coal dust with the stone dust, both of which were brought to the same degree of fineness by pulverising in a disintegrator.

| Experiment No. | Mixture. | | Quantity of mixture per cubic foot of air space of gallery. | Result. |
|---|---|---|---|---|
| | Coal dust. | Stone dust. | | |
| | Per cent. | Per cent. | Oz. | |
| 81 | 100 | *Nil* | 0·2 | Explosion (*see* Table I.) |
| 80 | 90 | 10 by weight * | 0·2 | Ignition only. Flame propagated 110 ft. in front of point of ignition. No pressure. |
| 82 | 90 | 10 | 0·4 | Explosion. |
| 84 | 80 | 20 | 0·4 | Ignition only. Flame propagated 80 ft. in front of point of ignition. No pressure. |
| 112 | 80 | 20 | 0·6 | Explosion. |
| 87 | 70 | 30 | 0·6 | Ignition only. Flame propagated 63 ft. in front of point of ignition. No pressure. |
| 89 | 70 | 30 | 0·8 | Explosion. |
| 90 | 60 | 40 | 0·8 | Ignition only. Flame propagated 165 ft. in front of point of ignition. No pressure. |
| 92 | 60 | 40 | 1·0 | Explosion. |
| 93 | 50 | 50 | 1·0 | No explosion. Evidence of flame only in vicinity of cannon shot, *i.e.*, 10 ft. |

* The specific gravity of the Silkstone coal dust is 1·298; that of the stone dust used was 2·58. (Water = 1·00).

To face page 106

TABLE I.

## EXPLOSIONS WITH MIXTURES OF COAL DUST AND STONE DUST.

In all these experiments a zone of 275 ft. was employed.
Ignition was effected at a point 275 ft. from downcast (*i.e.*, at the end of the dust-strewn zone) by the firing of a charge of 24 oz. of blasting powder from a cannon stemmed with 8 in. of dry clay.
The intake, from the downcast to the point of ignition, was set with props and bars every 9 ft.
An air current of 60,000 cubic feet per minute (velocity 1,200 ft. per minute) was drawn through the downcast at the time of the explosion.
Length of intake = 600 ft. Sectional area = 41 square feet. Length of return = 295 ft. Sectional area = 28 square feet.

| Experiment No. | 81 | 80 | 82 | 84 | 112 | 87 | 89 | 90 | 92 | 93 |
|---|---|---|---|---|---|---|---|---|---|---|
| Date | August 26, 1909 | August 24, 1909 | August 27, 1909 | August 30, 1909 | October 11, 1909 | September 6, 1909 | September 7, 1909 | September 8, 1909 | September 10, 1909 | September 11, 1909 |
| Mixture | Pure coal dust | 10 per cent. stone dust | 10 per cent. stone dust | 20 per cent. stone dust | 20 per cent. stone dust | 30 per cent. stone dust | 30 per cent. stone dust | 40 per cent. stone dust | 40 per cent. stone dust | 50 per cent. stone dust |
| Quantity :— | | | | | | | | | | |
| Per lineal foot | ½ lb. | ½ lb. | 1 lb. | 1 lb. | 1½ lb. | 1½ lb. | 2 lb. | 2 lb. | 2½ lb. | 2½ lb. |
| = per cubic foot | ·2 oz. | ·2 oz. | ·4 oz. | ·4 oz. | ·6 oz. | ·6 oz. | ·8 oz. | ·8 oz. | 1 oz. | 1 oz. |
| Fineness :— | | | | | | | | | | |
| Remaining on 100 mesh | 3·5 per cent. | 4·15 per cent. | 8·65 per cent. | 3·25 per cent. | 6·10 per cent. | 5·25 per cent. | 4·10 per cent. | 6·10 per cent. | 2·5 per cent. | 1·0 per cent. |
| Through 100 on 150 | 8·0 ,, | 4·40 ,, | 2·00 ,, | 7·65 ,, | 4·25 ,, | 7·20 ,, | 8·20 ,, | 9·25 ,, | 6·0 ,, | 7·0 ,, |
| ,, 150 on 200 | 3·0 ,, | 2·80 ,, | 4·00 ,, | 3·00 ,, | 3·10 ,, | 2·20 ,, | 2·00 ,, | 2·10 ,, | 1·5 ,, | 9·0 ,, |
| ,, 200 on 240 | 7·0 ,, | 10·10 ,, | 8·00 ,, | 7·10 ,, | 10·20 ,, | 10·10 ,, | 8·10 ,, | 6·00 ,, | 13·5 ,, | 13·5 ,, |
| ,, 240 and finer | 78·5 ,, | 78·55 ,, | 77·35 ,, | 79·00 ,, | 76·35 ,, | 75·25 ,, | 77·60 ,, | 76·55 ,, | 73·5 ,, | 66·5 ,, |
| Meteorological conditions :— | | | | | | | | | | |
| Barometric pressure | 29·7 in. | 29·5 in. | 29·7 in. | 29·7 in. | 29·7 in. | 29·5 in. | 29·6 in. | 29·9 in. | 30·1 in. | 30·0 in. |
| External temperature— | | | | | | | | | | |
| Dry bulb | 63 degs. Fahr. | 61 degs. Fahr. | 63 degs. Fahr. | 55 degs. Fahr. | 63 degs. Fahr. | 66 degs. Fahr. | 52 degs. Fahr. | 56 degs. Fahr. | 57 degs. Fahr. | 56 degs. Fahr. |
| Wet bulb | 57 ,, ,, | 58 ,, ,, | 56 ,, ,, | 50 ,, ,, | 59 ,, ,, | 61 ,, ,, | 47 ,, ,, | 50 ,, ,, | 52 ,, ,, | 52 ,, ,, |
| Internal temperature— | | | | | | | | | | |
| Dry bulb | 71 ,, ,, | 63 ,, ,, | 61 ,, ,, | 59 ,, ,, | 69 ,, ,, | 67 ,, ,, | 58 ,, ,, | 67 ,, ,, | 60 ,, ,, | 62 ,, ,, |
| Wet bulb | 61 ,, ,, | 61 ,, ,, | 58 ,, ,, | 52 ,, ,, | 63 ,, ,, | 62 ,, ,, | 54 ,, ,, | 58 ,, ,, | 55 ,, ,, | 58 ,, ,, |
| Per cent. saturation— | | | | | | | | | | |
| External | 67 per cent. | 82 per cent. | 63 per cent. | 70 per cent. | 82 per cent. | 73 per cent. | 69 per cent. | 65 per cent. | 70 per cent. | 75 per cent. |
| Internal | 53 ,, | 88 ,, | 82 ,, | 61 ,, | 68 ,, | 73 ,, | 76 ,, | 56 ,, | 71 ,, | 77 ,, |
| Direction of wind | North-west | South-west | North-west | North-west | South-east | West | North-west | North-north-west | North-north-east | North-north-east |
| Velocity of wind | 11 miles per hour | 4 miles per hour | 7 miles per hour | 1 mile per hour | 9 miles per hour | 5 miles per hour | 7 miles per hour | 10 miles per hour | 8 miles per hour | 5 miles per hour |
| General state of weather (at time of experiment) | Fine, 1 p.m. | Dull, 10.30 a.m. | Dull, 10.30 a.m. | Dull, inclined to rain, 1.20 p.m. | Fair, 1.35 p.m. | Raining, 11.15 a.m. | Overcast, 4.50 p.m. | Fair, 1 p.m. | Fine, 1.20 p.m. | Fine, 11.30 a.m. |
| | Explosion. Flame projected 130 ft. from downcast. Tub sent 414 ft. | Inflammation only. Flame travelled 110 ft. in front of point of ignition. No pressure developed. | Explosion. Flame projected 130 ft. from downcast. Tub sent 320 ft. | Inflammation only. Flame travelled 80 ft. in front of point of ignition. No pressure developed. | Explosion. Flame projected 130 ft. from downcast. Tub sent 196 ft. | Inflammation only. Flame travelled 63 ft. in front of point of ignition. No pressure developed. | Explosion. Flame projected 150 ft. from downcast. Tub sent 350 ft. | Inflammation only. Flame travelled 165 ft. in front of point of ignition. No pressure developed. | Explosion. Flame projected 165 ft. from downcast. Tub sent 410 ft. | No explosion. Evidence of flame near cannon up to 10 ft. No pressure developed. |
| Maximum pressure recorded | 11 lb. per sq. in. | | 4·5 lb. per sq. in. | | 8·9 lb. per sq. in. | | 8 lb. per sq. in. | | 8·4 lb. per sq. in. | |

The general conclusion to be drawn from these results is that as the percentage of inert matter in the dust is increased, so must the total quantity of mixture per cubic foot of air be augmented in order that the flame may be propagated with explosive violence ; while when the combustible and incombustible dusts are present in equal proportion, flame is not propagated even with a large excess of the mixture.

In the first experiment in the foregoing table (No. 81), pure coal dust was present in quantity corresponding to nearly twice the theoretical amount required to utilise all the oxygen in the air.* At first sight it might appear that this should form a more explosive mixture than one containing a greater excess of coal dust, for any excess either should remain inert, or might exercise a retarding effect by cooling the flame.†

On consideration, however, it would seem more likely that the presence of excess of coal dust would favour the propagation of flame ; for the reaction takes place between the *molecules* of oxygen on the one hand and the *particles* (aggregates of molecules), of coal dust on the other : so that anything which tends to increase the number of collisions between the oxygen molecules and the combustible dust will also increase the rapidity of combustion.‡

Looked at from this point of view, it would appear that a dust explosion can never, as it is sometimes supposed, be stifled by too great an excess of dust ; there cannot be a "higher limit," as in the case of gaseous explosions, but the oxygen, being by far the more mobile agent in the reaction, will merely combine with such coal as it requires and leave the remainder unburnt.

Subsequent to the passage of the explosion no doubt the excess of dust will enter into chemical reaction with the products of combustion, but, though such reactions may absorb heat, they will have no retarding effect upon the rate of propagation of flame, since it has already passed.

In support of such contentions, comparison may be made between Experiment No. 54 (page 108), and Experiment No. 81 just referred to. In the latter, a maximum pressure of only 11 lb. per square inch was recorded, while in the former, which was conducted with the same length of zone, but with twice the quantity of dust per cubic foot of air, a pressure of 50 lb. per square inch was attained.

Turning again to the experiments with mixtures of coal dust and stone dust, the reason for the behaviour of such mixtures becomes apparent in the light of the foregoing considerations.

The admixture of an inert dust with the coal dust acts in the same way as the admixture of an inert gas with an explosive gas mixture. The inert dust, like the inert gas, takes up heat from the contiguous molecules, and, not being combustible itself, reduces the average temperature. If the temperature is sufficiently reduced the flame cannot be propagated.§

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* The theoretical quantity of Altofts Silkstone coal required for the complete combustion of the oxygen in one cubic foot of air at 15 degs. Cent. and 760 mm. is ·1185 oz.

† Assuming that all the oxygen that has combined with the carbon of the coal dust has formed carbon dioxide, the presence of excess of carbon in the heated atmosphere would enable the reaction $CO_2 + C = 2CO$ to proceed. This reaction absorbs heat.

‡ It is for this reason also that the fineness of the dust is such an important factor in ensuring rapid propagation—greater fineness exposes greater surface to the bombardment by the oxygen molecules.

§ *See* Part II., Chapter I.

The extent to which admixture of so small a quantity as 10 per cent. of inert dust retards combustion is shown by comparison of Experiment No. 82 with No. 54. In both these the zone of 275 ft. of dust was present in the quantity of 0·4 oz. per cubic foot, but whereas No. 82 was with a mixture containing 10 per cent. of stone dust, No. 54 was with pure coal dust.

The main results were as follow :—

| Experiment No. | | Maximum pressure, lb. per square inch. | Mean velocity of propagation. |
|---|---|---|---|
| 82 | 10 per cent. stone dust ..... | 4·8 | 185 ft. per second |
| 54 | Pure coal dust ..... | 50·0 | 1,700 ft. per second |

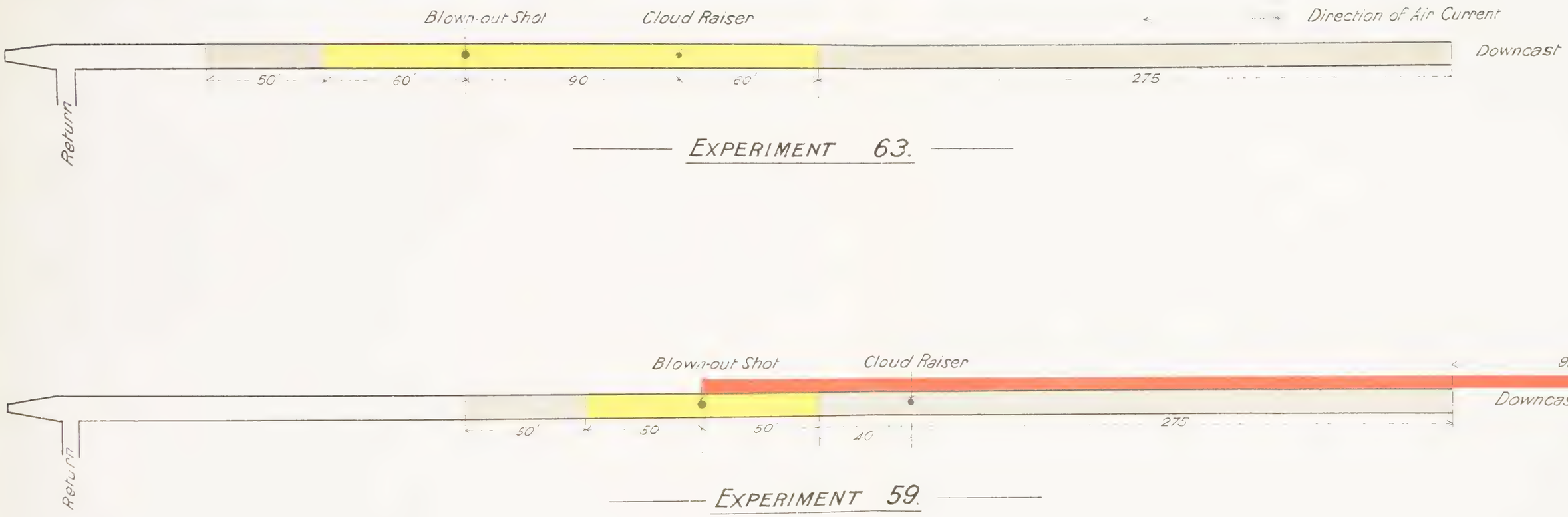
In Appendix I. to this report will be found the records of trial of the explosive nature of three South African coals. These trials form an interesting comparison with the stone dust mixture experiments, inasmuch as the samples of coal contained about 10, 15, and 20 per cent. of ash respectively. The similarity in behaviour between dusts containing such proportions of *natural* ash and the artificial mixtures is very marked. (*See* Appendix I.)

The effect of stone dust as a "zone" in the path of a coal dust explosion would seem to lie in its power of offering resistance to the projection of the flame of the explosion. That is to say, its action is mainly mechanical. The cloud of incombustible particles in the air immediately in front of the explosion presents a denser atmosphere offering greater resistance and prevents the flame of the explosion from penetrating so far as it would in dust-free air. At the same time it diminishes the danger of the flame of the explosion spreading through the cloud of unburnt coal dust driven in front, since it mixes with it and in this way raises its ignition point.* For stone dust to act in this way, however, it is essential that it must be fine enough to be raised as a cloud in the path of the explosion, and it has yet to be proved whether its action would be sufficiently rapid when dealing with an explosion that has travelled a longer distance *and has attained its maximum velocity of propagation.* The value of stone dust would appear to lie more in its use as a diluent, thus preventing an ignition, than in any specific action it may have in stopping an explosion that has once started. It would, therefore, seem advisable not to employ zones of any description, whether dustless, watered, or stone dust, in spite of the good results that have been given by the last-named when dealing with an explosion that has travelled 275 ft. The better principle would appear to be to treat with stone dust all places where coal dust can accumulate, and in this way guard against the primary ignition of coal dust; for it is a far easier matter to prevent an explosion ever occurring than to stop it after it has travelled some distance, and it is, without doubt, preferable to exclude all possibility of the formation of carbon monoxide by the combustion of even a few hundred pounds of coal dust.

* In this connection a recent paper by Messrs. Bedson and Widdas (*Trans.* Inst. Mining Engineers, vol. xxxiv. (1), p. 91) on the "Inflammability of Mixtures of Coal Dust and Air" is of great interest.

Stone Dust
Coal Dust
Flame

# PLATE XII.




EXPERIMENT 63.




EXPERIMENT 59.

## PLATE XII. SHOT FIRING EXPERIMENTS IN A STONE DUST ZONE.

# NOTE I.

## THE PRESSURE CURVES.

The manner in which the curves reproduced in this Report are plotted has already been described on page 75; as an example to render the process clear, and to give a notion of the accuracy with which reproduction can be made, the numbers from which curve 54B has been plotted may be quoted.

*Speed of Revolution of Manometer Drum.*—The distance equivalent to $\frac{1}{10}$ second = 6·02 cm.

In order to be able to compare the pressure records obtained in different experiments, it is necessary that all points determined on the curve should be reduced to the same time basis, for the speed of revolution of the drum will vary slightly from one experiment to another. The time basis chosen for the majority of the curves that are reproduced in this Report is $\frac{1}{10}$ second = 2·5 cm., such a reduction being necessary in order to avoid the use of long folding plates.*

In the Table given below, the first column of figures gives the actual position of the point read on the pressure curve on the circumference of the measuring machine drum. The second column gives the difference in distance between successive points. The third gives these distances summed consecutively; while in the fourth column, the figures in the third column are reduced to the standard unit of time. Column five gives the position of the base line of the pressure curve, and column six the position of the

| 1. | 2. | 3. | 4. | 5. | 6. | 7. | 8. |
|---|---|---|---|---|---|---|---|
| 27·55 | — | — | — | 9·285 | 9·057 | 0·228 | 6·0 |
| 26 62 | 0·93 | 0·93 | 0·38 | 9·259 | 9·039 | 0·220 | 5·8 |
| 24·54 | 2·08 | 3·01 | 1·25 | 9·242 | 8·991 | 0·251 | 6·6 |
| 22·20 | 2·34 | 5·35 | 2·22 | 9·219 | 8·940 | 0·279 | 7·1 |
| 19·39 | 2·81 | 8·16 | 3·43 | 9·174 | 8·913 | 0·261 | 6·7 |
| 17·32 | 2·07 | 10·23 | 4·25 | 9·101 | 8·880 | 0·221 | 5·8 |
| 19·59 | 0·73 | 10·96 | 4·55 | 9·157 | 8·901 | 0·256 | 6·7 |
| 15·14 | 1·45 | 12·41 | 5·15 | 9·150 | 8·914 | 0·236 | 6·1 |
| 13·78 | 1·36 | 13·77 | 5·72 | 9·122 | 8·836 | 0·286 | 7·4 |
| 12·35 | 1·43 | 15·20 | 6·21 | 9·062 | 8 735 | 0·327 | 8·4 |
| 10·70 | 1·65 | 16·85 | 6·90 | 9·080 | 8·659 | 0·421 | 10·8 |
| 9·99 | 0·71 | 17·56 | 7·29 | 9·049 | 8·529 | 0·520 | 13·2 |
| 8·81 | 1·18 | 18·74 | 7·76 | 9·025 | 8·379 | 0·646 | 16·5 |
| 8·01 | 0·80 | 19·54 | 8·11 | 9·966 | 8·171 | 0·795 | 20·1 |
| 7·25 | 0·76 | 20·30 | 8·43 | 8·940 | 8·027 | 0·913 | 22·3 |
| 6·87 | 0·38 | 20·68 | 8·59 | 8·931 | 7·890 | 1·041 | 24·9 |
| 6·60 | 0·27 | 20·95 | 8·70 | 8·959 | 7·842 | 1·117 | 26·2 |
| 6·52 | 0·08 | 21·03 | 8·73 | 8·939 | 7·699 | 1·240 | 28·6 |
| 6·23 | 0·29 | 21·32 | 8·85 | 8·951 | 7·593 | 1·358 | 30·8 |
| 6·18 | 0·05 | 21·37 | 8·87 | 8·969 | 7·381 | 1·588 | 35·1 |
| 5·51 | 0·67 | 22·04 | 9·15 | 8·956 | 7·381 | 1·575 | 34·9 |
| 5·35 | 0·16 | 22·20 | 9·22 | 8·960 | 7·505 | 1·455 | 32·7 |
| 4·96 | 0·39 | 22·59 | 9·33 | 8·899 | 7·534 | 1·365 | 31·0 |
| 4·06 | 0·90 | 23·49 | 9·75 | 8·915 | 7·880 | 1 035 | 24·7 |
| 3·60 | 0·46 | 23·95 | 9·945 | 8·917 | 7·988 | 0·929 | 22·7 |
| 2·31 | 1·29 | 25·24 | 10·48 | 8·890 | 7·972 | 0·918 | 22·5 |
| 2·11 | 0·20 | 25·44 | 10·50 | 8·853 | 8·030 | 0·823 | 20·7 |
| 1·22 | 0·89 | 26·33 | 10·56 | 8·918 | 8·229 | 0·689 | 17·6 |
| 1·12 | 0·10 | 26·43 | 10·93 | 8·886 | 8·150 | 0·736 | 19·0 |
| 0·40 | 0·71 | 27·14 | 10·97 | 8·886 | 8·109 | 0·777 | 19·7 |
| 49·84 | 0·57 | 27·71 | 11·27 | 8·850 | 8·134 | 0·716 | 18·3 |
| 48·85 | 0·99 | 28·70 | 11·51 | 8·790 | 8·200 | 0·590 | 15·0 |
| 47·78 | 1·07 | 29·77 | 11·92 | 8·705 | 8·287 | 0·418 | 10·7 |
| 47·65 | 0·13 | 29·90 | 12·36 | 8·716 | 8·329 | 0·387 | 10·0 |
| 47·59 | 0·06 | 29·96 | 12·42 | 8·703 | 8·431 | 0·272 | 7·0 |
| 46·88 | 0·71 | 30·67 | 12·44 | 8·669 | 8·280 | 0·389 | 10·0 |
| 46·40 | 0·48 | 31·15 | 12·46 | 8·651 | 8·435 | 0·216 | 5·6 |
| 46·12 | 0·28 | 31·43 | 12·93 | 8·689 | 8·401 | 0·288 | 7·5 |
| 45·91 | 0·21 | 31·64 | 13·05 | 8·661 | 8·366 | 0·295 | 7·7 |
| 45·61 | 0·30 | 31·94 | 13·14 | 8·625 | 8·360 | 0·265 | 6·9 |
| 45·57 | 0·04 | 31·98 | 13·26 | 8·616 | 8·379 | 0·237 | 6·1 |
| 45·29 | 0·28 | 32·26 | 13·28 | 8·579 | 8·399 | 0·180 | 4·7 |
| 44·30 | 0 99 | 33·25 | 13·40 | 8·551 | 8·415 | 0·136 | 3·7 |
| 43·60 | 0·70 | 33·95 | 13·80 | 8·537 | 8·409 | 0·128 | 3·4 |
| 43·21 | 0·39 | 34·34 | 14·09 | | Zero | | |

Joint in paper chart = 1·11 cm.

* The pressure curves for the wood charcoal explosion (106 A and B) are reduced to a time basis of 1 cm. = $\frac{1}{10}$ second.

| 1. | 2 | 3. | 4. | 5. | 6. | 7. | 8. |
|---|---|---|---|---|---|---|---|
| 40·73 | 1·37 | 35·71 | 14·83 | | | Zero | |
| 39·75 | 0·98 | 36·69 | 15·24 | 8·945 | 8·814 | 0·131 | 3·6 |
| 39·75 | 0·98 | 36·69 | 15·24 | 8·945 | 8·814 | 0·132 | 3·6 |
| 39·29 | 0·46 | 37·15 | 15·43 | 8·941 | 8·809 | 0·132 | 3·6 |
| 38·81 | 0·48 | 37·63 | 15·63 | 9·009 | 8·868 | 0·141 | 3·7 |
| 36·82 | 1·99 | 39·62 | 16·45 | | | Zero | |
| 36·55 | 0·27 | 39·89 | 16·57 | | | Zero | |
| 36·19 | 0·36 | 40·25 | 16·71 | 9·106 | 8·981 | 0·125 | 3·4 |
| 34·55 | 1·64 | 41·89 | 17·40 | 9·173 | 9·030 | 0·143 | 3·8 |
| 32·00 | 2·55 | 44·44 | 18·45 | 9·235 | 9·102 | 0·133 | 3·6 |
| 31·51 | 0·49 | 44·93 | 18·65 | 9·242 | 9·130 | 0·112 | 3·0 |
| 30·26 | 1·25 | 46·18 | 19·17 | | | Zero | |
| 30·19 | 0·07 | 46·25 | 19·21 | | | Zero | |
| 30·09 | 0·10 | 46·35 | 19·25 | 9·271 | 9·020 | 0·251 | 6·5 |
| 30·02 | 0·07 | 46·42 | 19·28 | 9·291 | 9·049 | 0·242 | 6·2 |
| 29·99 | 0·03 | 46·45 | 19·29 | 9·278 | 9·071 | 0·207 | 5·4 |
| 29·91 | 0·08 | 46·53 | 19·32 | 9·240 | 8·992 | 0·248 | 6·3 |
| 29·85 | 0·06 | 46·59 | 19·35 | 9·242 | 8·979 | 0·263 | 6·8 |
| 29·76 | 0·09 | 46·68 | 19·38 | 9·240 | 9·061 | 0·179 | 4·7 |
| 28·88 | 0·88 | 47·56 | 19·74 | 9·231 | 9·015 | 0·216 | 5·6 |
| 27·55 | 1·33 | 48·89 | 20·34 | 9·285 | 9·057 | 0·228 | 6·0 |

points on the curve itself relative to this base line. Column seven gives the difference in millimetres between these last two sets of numbers, and column eight their equivalents in pounds per square inch pressure.

The curve is plotted from columns four and eight.

## CHAPTER VII.

# APPLICATION OF STONE DUST AT ALTOFTS COLLIERIES.

CHAPTER VII.

## APPLICATION OF STONE DUST AT ALTOFTS COLLIERIES.

It was considered by the Committee that tests should be carried out underground as to the best means of applying stone dust, with a view to ascertaining the cost, &c. They therefore requested the management of the Altofts Collieries to make the necessary trials.

As a first step it was necessary to obtain some notion of the rate at which coal dust was being deposited in various parts of the mine, in order to be able to determine the quantity of stone dust that would be required per linear yard of roadway. To test this, in September 1908 shelves were fixed to timbers along one of the main haulage roads, and a certain quantity of stone dust placed upon them ; the quantities of coal dust deposited during different lengths of time were then determined.

This information having been obtained, it was decided to treat certain lengths of the main haulage roads with stone dust in the quantity necessary. These lengths or "zones" were begun in December 1908.

Three principal seams are worked at the Altofts Collieries, the Haigh Moor (4 ft. thick, 135 yards deep), the Silkstone (4 ft. thick, 320 yards deep), and the Diamond (3 ft. 3 in. thick, 500 yards deep). The seams lie practically level.

The Silkstone and Diamond workings are dry, but the Haigh Moor workings are generally damp.

Each seam has its own downcast and winding shaft, but the workings are connected by various shafts and cross-measure drifts. Some of the workings in the Haigh Moor and Silkstone seams are 3 miles from the downcast shafts.

At first the lengths of road to be treated with stone dust were selected with the object of isolating the various parts of the pits by means of zones 200 yards in length, thus cutting off each district from the haulage roads, each haulage road from every other haulage road, and each seam from every other seam. As an extra precaution wooden shelves carrying large quantities of stone dust were placed for 20 or 30 yards at either end of some of the zones, overhead or along the sides, according as height or width permitted.

Further consideration made it apparent, however, that although such zones might have the effect of preventing a firedamp explosion from spreading to the coal dust on the haulage roads, and might also be capable of checking a coal dust explosion that had only travelled a short distance, it was preferable to adopt every possible precaution that might render *all* the coal dust present in the mine inert, and thus incapable of either originating or propagating an explosion.

An additional reason for this decision, and one that weighed considerably with those responsible for the safety of the mine, was the danger, if the zone system were adhered to, of the combustion of even a few hundred pounds of coal dust forming sufficient carbon monoxide to endanger the lives of the workmen in the mine.

For supposing that only 100 lb. of the carbon contained in a certain quantity of coal dust are burned to form carbon monoxide, the quantity of this gas produced would be several thousand cubic feet. This would be sufficient to render poisonous over a million cubic feet of fresh air, if mixed with it in the proportion of 0·2 per per cent. (*See* note by Dr. J. S. Haldane, page 119.)

It was therefore decided that the principle to be employed must be *to treat with stone dust all places where coal dust is liable to accumulate*, special attention being directed to the haulage roads.

If this practice had been in force in the Silkstone Seam at Altofts before the explosion in 1886, it is the opinion of those who recovered the pit, and have since witnessed the British coal dust experiments, that ignition of coal dust might have been prevented, and that in any case explosion would not have been propagated along the roads. For the roads on which destruction was observed are the only ones which would have required treating in the manner now adopted. (*See* Plate XIII.)

The roads coloured pink in this plan are the haulage roads. Large quantities of fine coal dust had accumulated on these roads owing to the system of haulage being by chain, which, when the tubs were not fed regularly, dragged on the floor and ground to powder any pieces of coal that had fallen from the tubs. The roads coloured blue and green are those upon which nothing but stone dust could be present owing to the method of working being longwall, so that pack walls had taken the place of the coal seam. The sides and roof of the return roads were formed by stone from the ripping, and the floor was in fireclay. This fireclay had been worn away to a depth of 12 or 18 inches by the tramping of men and horses, and, since it was the main travelling road, the fine dust thus formed was continually being raised in suspension, and the whole perimeter of the roadway was covered with fine incombustible dust.

## PREPARATION OF THE STONE DUST.

The strata overlying the various seams consist principally of strong grey or blue binds. For convenience, the bind overlying the Diamond seam has been chiefly used.

The dust is prepared in a steam-driven twin-roller mill ordinarily used for grinding mortar.* The stone sent out of the pits for the purpose is as small and free from ironstone as possible, and it is usually selected from that obtained in the course of widening or repairing roads which have been subjected to considerable crushing, since such stone dust is easier to grind than freshly-wrought solid ground.

*To obviate the necessity of sending stone out of the pit to be ground, and to utilise the fine dust formed during grinding, a special form of ball mill, driven by compressed air, has also been installed at the pit bottom. This mill requires very little attention and is, therefore, placed in charge of the hooker-on. Its use enables the coal dust that is carried into the pit from the screens by the downcast air to be diluted with stone dust; it is put into operation after the men have left the pit, and thus dilutes during the afternoon or night the coal dust which has been carried down from the screens during the day shift.

The cost of winding the stone, conveying it to the mill, and returning the dust to the pit bottom ready for use might be neglected, since the quantity is small and little extra labour is entailed.

The estimated cost of grinding, including labour, steam, depreciation and repairs, does not exceed 2s. per ton of stone dust ground.

## APPLICATION UNDERGROUND AT ALTOFTS.

The dust having been sent down the pits in tubs holding about 15 cwts., two lads take it to the place appointed, and, working with their backs to the ventilating current, throw it in handfuls against the sides and roof, and over the top of the timbers, thus dislodging the coal dust and covering all surfaces with white stone dust. While treating the roof and sides in this way, a large quantity of stone dust falls to the ground, but an extra quantity is scattered there if required; this dust is disturbed by the men while passing along the roads, and the dust cloud thus formed afterwards settles upon the bar tops and sides of the roadway in the same way as would coal dust. If there is an excess of coal dust on the floor of the road it is usual to clean it up into tubs before applying the stone dust.

Two points are especially noticeable when stone dust is applied in this way :—

1. The stone dust displaces the coal dust from the ledges and timbers, and takes its place. Most of the coal dust falls to the floor with the excess of stone dust, but some of the finest of both dusts is carried inbye by the ventilating current.

2. Some of the stone dust sticks even to the vertical surfaces, and a length of road newly dusted has the appearance of having been whitewashed. If the work has been properly done, all ledges and other horizontal surfaces will be covered with stone dust as deep as the angle of repose will allow, and the crevices between the stones will also be partly filled with stone dust (figs. 71 and 72).

Where the sides of the roadway are bricked, or for any other reason are too smooth to retain the required amount of stone dust; or where it is considered advisable to have more stone dust than can be conveniently carried on the sides and timbers, shelves are put up for the purpose. The manner of doing this has been governed by the size of the road and the method of timbering. Where there is sufficient height the shelves are carried overhead, but where there is not sufficient height they are fastened along the sides to the props or brickwork. There are various methods of supporting the shelves, some of which are shown in the accompanying photographs (figs. 73 to 76).

As soon as the white appearance of the stone dust is lost, owing to the deposit of coal dust, it is considered advisable to give another dressing. Since, although the actual percentage of coal dust thus deposited would only be small if the whole quantity of mixed dusts were raised in suspension, it is conceivable that the lighter coal dust lying upon the stone dust might be raised more readily by an explosion of small force, and might thus enable propagation to take place.

At the Altofts Collieries, where the system of haulage is mostly that of slow moving endless rope, and where the tubs (a large proportion of which are iron) are kept tight, one dressing in twelve months along the main haulage roads appears to be

sufficient. Two hundred yards on the inbye sides of main junctions require dressing twice a year, and the roads near the shaft bottom are treated every three months.*

The boys who distribute the dust are provided with overalls. So far no need has been found for goggles or respirators, as the haulage roads are also the main intakes, and there is always a brisk air current to carry forward the dust.

The tools used are two buckets and a shovel. Small tin scoops with handles have been tried, but without any advantage, since the dust spreads better and is thrown straighter with the bare hand.

## COST PER YARD AT ALTOFTS.

The cross-sectional area of the roads treated is from 50 to 60 square feet. The quantity of dust used on the first application is five tubs per hundred linear yards, or about $\frac{3}{4}$ cwt. per yard, and two lads are able to dust about 125 yards per shift; these lads are paid 3s., plus percentage, or about 4s. 5d. per day.

The cost of treating such roads is therefore :

| | Per yard. |
|---|---|
| Wages underground ..... | 0·85d. |
| Cost of preparing dust, $\frac{3}{4}$ cwt. at 2s. per ton ..... | 1·00d. |
| | 1·85d. |

At junctions and shaft bottoms the quantity of dust and the labour required is rather more.

Subsequent dressings do not need to be so heavy.

To the above, the cost of labour for cleaning up the excess of mixed dusts, which shonld be done from time to time, may be added.†

## COST OF DRESSING PER TON OF COAL RAISED AT ALTOFTS.

As an example of the total cost of applying the stone dust remedy underground, the case of the Silkstone Seam may be given.

The total length of mechanical haulage roads is 6,100 yards, to which further lengths at the junctions, amounting in the aggregate to 800 yards, must be added.

If the whole of this length were dressed twice a year, the cost of dressing works out at about one-eighth of a penny per ton of coal raised.

* The time that should be allowed to expire before the dressing of stone dust on any particular road is renewed depends entirely on the rate at which the coal dust is deposited. This will be governed, among other things, by the quantity of coal drawn, the nature and friability of the coal worked, the condition of the tubs, the system and rate of haulage, and the speed of the ventilating current. Another important factor is whether the roads are made in coal or in stone. If they are made in the coal a large quantity of small coal and dust is continually being made by the crushing of the pillars. This is obviated by working out the whole of the coal by the longwall pack-gate system, which is now generally done in deep pits. The sides of the roads by this method consist of stone surfaces instead of coal, due to the ripping and packing.

The position of the screens on the surface in relation to the downcast is important with regard to the rate of deposition of coal dust near the pit bottom.

In general, it will probably be found that renewal will have to be most frequent near junctions and shaft bottoms.

† The cost of filling up road cleanings of equal weight to the first dressing of stone dust would be 0·33d. per yard

To face page 116.

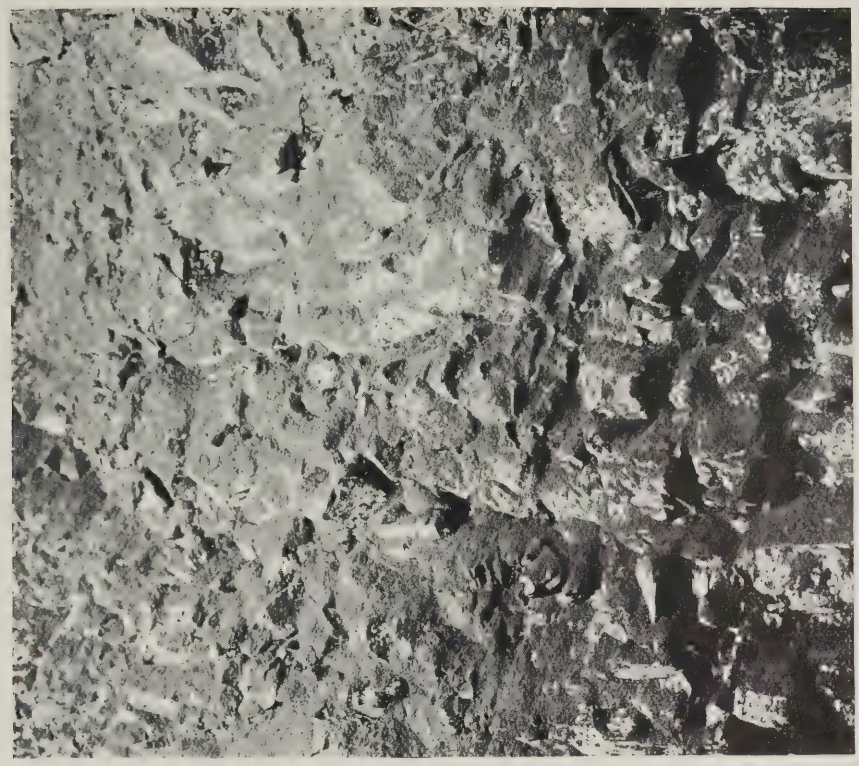


Fig. 71.—Showing the numerous ledges on which Coal Dust is deposited on the side of the main haulage road.

Stone Dust. Coal Dust.

Fig. 72.—Side of main haulage roadway partly treated with Stone Dust.

Fig. 73.—Method of applying extra Stone Dust in a main haulage road where height permits.

Fig. 74.—Another view of the above.

Fig. 75.—Another method of applying Stone Dust in a main haulage road where height permits.

Fig. 76.—Another method of applying Stone Dust in a main haulage road where width permits.

## COST OF DRESSING PER TON OF COAL RAISED AT NEW MOSS.

Figures are also available for the cost of treatment of steep underground workings at the New Moss Collieries, Ashton, which are practically under the same management as the Altofts Collieries. These figures serve to show the difference in cost that may be expected when dealing with a steep mine. The average gradient at New Moss is 12 in. per yard, or 19 degs.

The main difference, as reported by the management, appears to lie in the cost of wages underground. Owing to the heavy work of moving the tubs containing the stone dust, men are employed instead of lads in the brows. Two men put on two tubs in three hours, the length of roadway covered being 25 yards. Their wages per day amount to 10s. 9d., so that, since they are employed during three-eighths of a day, the cost for putting on two tubs of stone dust is 4s. 1d., or 2d. per yard of roadway.

The brows require $1\frac{1}{4}$ cwts., and the levels $\frac{3}{4}$ cwt. per yard for the first dressing, and renewal would appear to be necessary once a year for all parts of the pit except the first 500 yards of each intake road, which are being treated every three months.

The cost of preparing the dust can be taken as being the same as at Altofts.

The total length of roadway requiring treatment at this colliery is as follows :—

| | Yards. | Number of dressings per year. | Cost per yard per dressing. | Total cost per annum. |
|---|---|---|---|---|
| | | | d. | £ s. d. |
| Main haulage brows | 700 | 4 | $3\frac{2}{3}$ | |
| Main haulage brows | 800 | 1 | $3\frac{2}{3}$ | 83 15 4 |
| Jig brows, &c. | 1,880 | 1 | $3\frac{2}{3}$ | |
| Main levels | 750 | 4 | 2 | |
| Main levels | 5,000 | 1 | 2 | 66 13 4 |
| | | | | 150 8 8 |

Since the output from the colliery is about 420,000 tons per year, the cost of dressing with stone dust per ton of coal raised works out at about one-tenth of a penny.

On comparing the figures for the two mines it will be seen that the increased cost in a steep mine as compared with a level mine amounts to about £35, or 30 per cent., for almost the same yardage ; 13,480 yards being dressed at New Moss and 13,800 at Altofts.

The larger output at New Moss (due to that colliery working double shift) brings the cost of dressing per ton of coal raised to practically the same as that of Altofts.

## CHARACTER AND COMPOSITION OF DUST SUITABLE.

Any incombustible dust, if capable of being readily raised in suspension, will serve the purpose if the fact of preventing explosion be alone considered. The effect of such dust on the health of workmen, especially of those who are employed in distributing the dust, must also be taken into account.

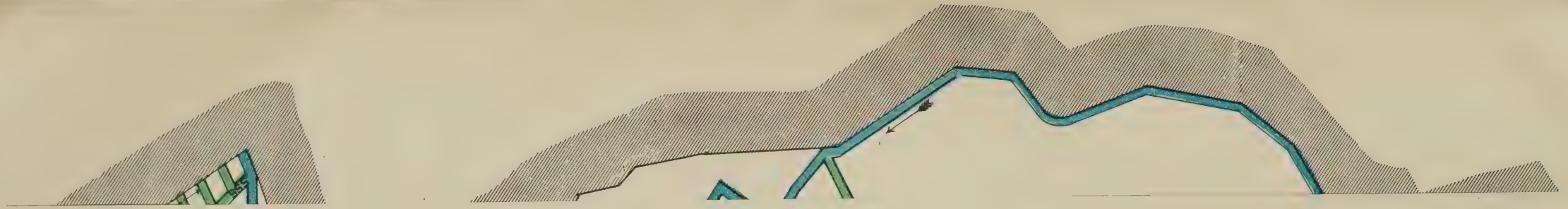
In this connection, Dr. J. S. Haldane has kindly contributed the accompanying note. He has treated the matter so fully that it is unnecessary to do more than

emphasise his warning that dust which contains a large proportion of hard material, such as quartz or sandstone, should not be used. Attention is also directed to his emphatic statement regarding the harmlessness of such substances as china clay, or the soft shale that is being used at Altofts Collieries, similar shales to which are found in most collieries near the coal seam.

The chemical analyses of the Altofts soft shale, and of china clay, as well as the average analyses of a sample of ordinary sand, are as follow :—

| | Altofts shale. | China clay. | Sand. |
|---|---|---|---|
| | Per cent. | Per cent. | Per cent. |
| Silica | 56·9 | 47·98 | 87·5 |
| Iron oxide and alumina | 27·1 | 38·80 | 2·4 |
| Lime | 1·2 | 0·24 | 4·3 |
| Magnesia | 2·2 | — | 0·7 |
| Alkalis | 4·0 | 0·16 | — |
| Combined water | 7·9 | 12·82 | 4·8 |

The silica in the Altofts shale and the china clay appears to be combined with alumina as aluminium silicate. Sand consists practically entirely of uncombined or "free" silica.



# ALTOFTS COLLIERY — SILKSTONE PIT EXPLOSION 2ND. OCTOBER 1886.

PLATE XIII.

## PLAN SHOWING THE ROADWAYS, COAL FACE AND WORKING PLACES; SYSTEM OF VENTILATION AND MAIN HAULAGE ROADS WITH FALLS OF ROOF.

| REFERENCE. | |
|---|---|
| DD | DOORS |
| SS | SHEETS |
| X | OVERCAST |
| | STOPPING |
| | DIRECTION OF WIND |
| | INTAKE |
| | RETURN |
| | FALLS OF ROOF |
| | HORSE ROADS |
| N | CAUTION BOARD |
| ○ | DOWNCAST |
| ○ | UPCAST |
| D | SCALE |
| L | LAMP STATION |
| ∴ | DEAD |

Length of Roadways open at the time of Explosion about.... 21 miles.
Area of Goaf about ..... 850 acres.

*Special attention is directed to the Falls of Roof, shewn in Red, on the Straight Main Haulage Roads where Coal Dust had accumulated. Also to the Gateways (Coloured GREEN) Return Air ways (BLUE), and other Roads (PINK), where no Falls or Damage were found. Such Roads were practically in Stone, due to the Dirt Pack, the four feet of Ripping Stone (to increase the height of Roadways) and the Stone Debris covering the Floor In short where Coal Dust existed destruction followed, but no damage was found on Stone Dust Roads.*

Scale, 10 Chains to One Inch

## NOTE II.

### THE PHYSIOLOGICAL EFFECT OF STONE DUST.

The following is a copy of a letter from Dr. J. S. Haldane, F.R.S., &c. :—

" Oxford,

" 21st January, 1910.

" Dear Mr. Garforth,

" You have asked me for a reasoned opinion as to whether the application of stone dust on mine " roads for preventing or stopping coal dust explosions could have any deleterious effects on the health of " the men who use those roads, and who might inhale some of the stone dust.

" There can be no doubt that certain kinds of stone dust or other inorganic dust produce, when " inhaled in sufficient quantity, a very serious tendency to lung diseases—particularly to bronchitis and " tubercular phthisis. Metalliferous miners who work in hard stone are apt to suffer severely in this way. " In order to show the effects, if any, of dust inhalation on the health of miners, I have compiled the " following table from data contained in the last Decennial Supplement (Part II., published in 1908) to " the Annual Reports of the Registrar-General, and in the Report to the Home Secretary by Messrs. " Martin and Thomas and myself on 'The Health of Cornish Miners.' "

DEATH-RATES, ENGLAND AND WALES, 1900-1-2, PER 1,000 LIVING AT EACH AGE.

| | Age 15-20. | | | | Age 20-25. | | | | Age 25-35. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Lung disease. | Accident. | Other causes. | Total. | Lung disease. | Accident. | Other causes. | Total. | Lung disease. | Accident | Other causes. | Total. |
| All occupied males | 0·8 | 0·4 | 1·2 | 2·4 | 2·0 | 0·5 | 1·9 | 4·4 | 2·8 | 0·6 | 2·6 | 6·0 |
| Coal miners | 0·7 | 1·2 | 1·3 | 3·2 | 1·4 | 1·2 | 1·9 | 4·5 | 1·6 | 1·2 | 2·1 | 4·9 |
| Ironstone miners | 1·0 | 1·6 | 0·5 | 3·1 | 0·7 | 0·7 | 1·6 | 3·0 | 1·9 | 1·5 | 1·9 | 5·3 |
| Miners living in Cornwall | 0·7 | 0·5 | 0·5 | 1·7 | 2·7 | 1·7 | 1·4 | 5·8 | 17·3 | 0·8 | 2·8 | 20·9 |
| Agricultural labourers | 0·5 | 0·4 | 0·8 | 1·7 | 1·3 | 0·6 | 1·6 | 3·5 | 1·5 | 0·5 | 2·1 | 4·1 |

| | Age 35-45. | | | | Age 45-55. | | | | Age 55-65. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| All occupied males | 4·4 | 0·7 | 5·1 | 10·2 | 6·3 | 1·0 | 10·4 | 17·7 | 8·7 | 1·3 | 21·0 | 31·0 |
| Coal miners | 2·4 | 1·6 | 3·6 | 7·6 | 4·8 | 2·1 | 7·8 | 14·7 | 12·0 | 2·8 | 21·2 | 36·0 |
| Ironstone miners | 2·4 | 1·4 | 2·8 | 6·6 | 5·6 | 1·4 | 5·2 | 12·2 | 8·7 | 3·0 | 16·3 | 28·0 |
| Miners living in Cornwall | 33·2 | 0·6 | 5·2 | 39·0 | 32·2 | 1·3 | 11·1 | 44·6 | 42·6 | 0·5 | 27·4 | 70·5 |
| Agricultural labourers | 2·0 | 0·7 | 3·3 | 6·0 | 3·1 | 0·9 | 6·6 | 10·6 | 4·4 | 1·3 | 13·6 | 19·3 |

| | Age 15-25. | | | | Age 25-35. | | | | Age 35-45. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Coal miners, 1849-53 (average for Staffordshire, South Wales, and Durham | 3·5 | 5·6 | 5·2 | 14·3 | 3·1 | 5·3 | 6·1 | 14·5 | 3·7 | 6·2 | 7·3 | 17·2 |
| | Age 45-55. | | | | Age 55-65. | | | | | | | |
| | 7·1 | 6·9 | 12·3 | 26·3 | 16·3 | 6·0 | 21·8 | 44·1 | | | | |

" The figures for miners living in Cornwall in 1901-02 show in a very marked degree the effects " produced by inhalation of dust particles from hard stone. That the increased death rate was due to this " and no other cause is shown in detail in the Home Office Report just referred to. It will also be seen " that the danger from dust entirely dwarfed every other danger to which these miners are exposed. A " large number of the deaths were due to work in the Transvaal mines or elsewhere out of England, but " the common cause was always easily traceable, and there could be no doubt that among the men most " exposed (those working rock drills without precautions against dust inhalation) the death rate was many " times higher than the figures in the table show. In other occupations, where men are more or less

" exposed to inhalation of dust particles from hard stone, steel, &c., there is a similar, though not so " serious, increase of deaths from lung diseases, including phthisis. The case of potters (who are more or " less exposed to dust from ground flint) or of grinders may be instanced, or that of men employed in " dressing hard sandstone for building purposes.

" There are few dustier occupations than that of a collier ; but on turning to the death rates for coal " miners we see that at every age up to 55 the death rate from lung diseases is very markedly below the " average for occupied males, and, indeed, is almost as low as for agricultural labourers. An enormous " change for the better has also occurred during the last 50 years since statistical information first became " available. It is clear, therefore, that the conditions of life of English colliers are very healthy, and the " dust inhaled, although it turns the lungs black, does not do much harm. It will be noticed, however, " that beyond the age of 55 colliers become somewhat disproportionately liable to lung diseases (mainly " bronchitis), and there can be little doubt that this is due to the dust which they have inhaled. The " comparatively healthy, industrial and social conditions under which colliers live are more than sufficient " to outweigh any bad effects produced by dust inhalation before the age of about 55. At first sight it " might seem improbable that the effects of dust inhalation would only manifest themselves after perhaps " 40 years or more of exposure to the dust ; but all the statistics of dusty occupations show that the effects " are commonly delayed in this way, except in cases where a large amount of dangerous dust is inhaled, " as in the case of the rock drill men already referred to. We may thus conclude that the dust inhaled " by colliers does do some harm, but only a little, and in the later periods of life.

" If stone dust were applied along the roads of a colliery, there is no doubt that the men would " breathe some of it, as it would certainly be disturbed by the traffic to some extent. If this dust were " similar to that of the Cornish or Transvaal mines, it would undoubtedly produce serious effects on " health, sufficient, probably, to far outweigh any saving of life from prevention of explosions. There is " abundant evidence, however, that dust from soft stone produces little or no ill effect unless, perhaps, " when inhaled in very excessive quantity. The statistics in the table for ironstone miners are significant " in this respect. A good deal of dust is produced in drilling, blasting and transporting ironstone in " ironstone mines, but it will be seen that ironstone miners remain very free of lung disease, even up to " old age. There are also a number of occupations, such as cement making or the getting of china " clay, in which men inhale large quantities of soft stone dust. From personal investigations I have never " been able to discover that lung disease is caused by these occupations, whereas the lung disease caused " by occupations associated with inhalation of dust from hard stone is almost a matter of popular " knowledge.

" The dust used at Altofts Colliery for stopping coal dust explosions is from soft shale, and is certainly " not of such a nature as to give rise to any anxiety as to the effects produced by inhaling it, particularly " as the amount inhaled would be small. According to Dr. Wheeler's analysis, it consists of hydrated " silicate of alumina and contains no free silica, whereas it is only the dust of stone consisting of or " containing free silica or other hard material that is dangerous. The dust from similar soft shale is, as " you have clearly pointed out, the most suitable and most readily available material in almost all English " collieries for using on roads to stop explosions. It would be well to point out, however, that dust from " hard stone, fireclay, sand or any material containing free silica, ought not to be employed. With this " precaution, I am confident that not the slightest risk to health would arise from the use of stone dust for " stopping explosions.

" Yours very truly,

" (Signed) J. S. Haldane."

## CHAPTER VIII.

# LABORATORY INVESTIGATIONS.

CHAPTER VIII.

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# LABORATORY INVESTIGATIONS.

## THE ACTION OF HEAT UPON COAL.

The main object of the work that is being conducted in the laboratory is to obtain information that will enable a distinction to be drawn between dusts of different degrees of inflammability or liability to propagate explosion, by determining such factors as (*a*) the temperature at which gas is most readily given off, (*b*) the stage in the heating at which the most inflammable mixture of gases makes its appearance, and (*c*) the shortest time of heating that will allow any gas at all to be distilled. All these factors determine the "ignition point" of the dust.

In this manner, by correlating the results obtained from the explosion in the gallery of a certain number (say, 20 or 30) of typical samples of coal dust as regards velocity of propagation of flame and pressure developed, with their behaviour under different modes of heat treatment in the laboratory, it should be possible to deduce from the latter alone whether a certain sample is capable of giving a dangerous dust, so that the labour and expense of the investigation can be reduced.

In all these questions, of course, the physical character of the coal—such as its density, friability, type of fracture and power of occluding gases—must also be taken into account.

### (*a*.) The Distillation of Coal.

In the course of experiments made to decide upon the best conditions for a standard determination of the volatile matter in coal, many trials were made as to the effect of distillation at different temperatures. The results were so interesting and seemed so likely to afford an indication as to the nature of the volatile constituents as to warrant an extension of the work.

A large number of distillations have been made with different samples of coal, and although the research can in no way be said to be completed, it may be interesting to record a few of the results, while reserving the majority for a future report. It would be unwise to draw any but very general conclusions at present from the results so far obtained, but there is every indication that it should be possible, at no distant date, to decide from similar laboratory experiments whether a certain coal is likely to propagate an explosion more readily than another, without actually putting it to the test in the gallery.

It is not intended to suggest that the composition of the volatile constituents of a coal is the sole determining factor of its inflammability, since, for example, the readiness with which fine dust can be formed, the density of the coal, and the quantity of mineral matter associated therewith, will all have their influence, and there is evidence that it is the fineness of the dust in particular that determines its

liability to ignition—assuming, of course, that the dust is combustible. Rather it is hoped to be able to show why, ignition once started, the dust from one coal is more likely than that from another coal to enable a disastrous explosion to be developed.

The lines upon which this research is proceeding will become apparent from a study of the following records. The distillations were made with the apparatus for determining the volatile matter which has already been described. In each case the experimental conditions were the same. Two grammes of the dried and sieved dust (which had passed through a 240 mesh) were mixed with three grammes of ignited silica sand in a platinum boat and placed in the retort, which was then connected to the gas-holder and exhausted. The retort was then pushed quickly into the electric furnace, which had previously been raised in temperature slightly higher than the distillation temperature required so as to compensate for the cooling effect of the introduction of the retort. The temperature recorded is the retort temperature, not that existing in the coal itself.

The records of the rate of evolution of the gas are taken from the moment that the pressure of the gas evolved is equal to atmospheric pressure, a minute or two usually being required before the vacuum in the retort was filled.

The quantity of gas evolved is calculated per gramme of ash-free, dry coal, as "nitrogen-free" gas at standard temperature and pressure (0 deg. Cent. and 760 millimetres).

The different constituents of the gas mixture evolved are calculated as percentages of the "nitrogen-free" mixture. From 1 to 4 per cent. of nitrogen is usually found in the mixtures, but since this may be due to the presence of traces of air in the retort connections, or to error in analysis,* it is thought best, for the purpose of comparison, to assume that the gases are free from nitrogen.

The quantities of tarry matter and of total volatile matter are calculated as percentages of the ash-free, dry coal, *i.e.*, as percentages of the pure combustible matter in the coal.

The main data recorded in Table II. are graphically represented in fig. 77, which shows the changes in percentages of the principal constituents of the gas, and of the tarry matter and volatile matter, as the distillation temperature is raised.

As might be expected, the higher the distillation temperature the higher is the percentage of total volatile matter and the larger is the volume of gas evolved. The quantity of tar appears to reach a maximum at the 700 degs. Cent. distillation, and then to gradually decrease.

The most noteworthy fact is the presence of a large percentage of ethane in the gases evolved at low temperatures, a percentage which decreases progressively with higher temperatures of distillation. It will be observed, however, that the *actual quantity* of ethane (and of methane) varies very little with the temperature of distillation, at any rate above 600 degs. Cent. This is shown more clearly in Table III., where the volumes, per gramme of coal, of each of the principal constituents evolved at each temperature have been calculated, and in fig. 78, which represents graphically the numbers thus obtained.

* Nitrogen cannot readily be determined directly, so that it is necessary to estimate the quantity present by subtracting the sum of all the other constituents from 100·00; consequently, in an analysis, the sum of the errors in the estimation of each constituent falls upon the nitrogen determination.

## THE DISTILLATION

This dust had the fol
sulphur = 2·93 ; and it contains

| | |
|---|---|
| Laboratory Experiment No. | A x |
| Distillation temperature ... | 500 deg |
| Rate of evolution of gas :— | |
| During 1st minute..... | 60 c.c. in |
| „ 2nd „ ..... | |
| „ 3rd „ ..... | |
| „ 4th „ ..... | |
| „ 5th „ ..... | |
| „ next 5 minutes.. | |
| „ „ 5 „ .. | |
| „ „ 15 „ .. | |
| „ „ 15 „ .. | |
| „ „ 30 „ .. | |
| Duration of heating ..... | 2 h |
| Total gas per gramme ash-free, dry coal .... ..... | 29·2 |
| Tarry matter per cent. .... | 9 |
| Total volatile matter per cent. | 18 |
| Gas analysis :— | |
| Benzene ..... ..... | 6 |
| Carbon dioxide ..... | 3 |
| Acetylene ..... | |
| Ethylene ..... | 1 |
| Carbon monoxide ..... | 6 |
| Hydrogen ..... | 16 |
| Methane ..... ..... | 37 |
| *Ethane ..... ..... | 27 |
| Remarks ..... | The conde ducts coloured sisted than of The gas very slo about to fill t atmospl sure. |

To face page 124.

## TABLE II.

### THE DISTILLATION OF DUST A (SILKSTONE NUTS) AT DIFFERENT TEMPERATURES.

This dust had the following ultimate analysis:—Carbon = 80·50; hydrogen = 5·45; oxygen = 9·70; nitrogen = 1·42; sulphur = 2·93; and it contained 5·51 per cent. of ash. The dried dust, after sieving through a 240 mesh sieve, was used.

| Laboratory Experiment No. | A xxxiv. | A xxiv. | A xxiii. | A xxii. | A xxi. | A xxxviii. | A xxxvi. |
|---|---|---|---|---|---|---|---|
| Distillation temperature ... | 500 degs. Cent. | 600 degs. | 700 degs. | 800 degs. | 900 degs. | 1,000 degs. | 1,100 degs. |
| Rate of evolution of gas:— | | | | | | | |
| During 1st minute ..... | 60 c.c. in 2 hours | 40 c.c. | 50 c.c. | 145 c.c. | 225 c.c. | 475 c.c. in first 3 minutes | 550 c.c. in first 3 minutes |
| „ 2nd „ ..... | | 25 | 25 | 75 | 125 | 25 | 10 |
| „ 3rd „ ..... | | 15 | 25 | 35 | 50 | 5 | 5 |
| „ 4th „ ..... | | 10 | 15 | 25 | 25 | | |
| „ 5th „ ..... | | 5 | 10 | 20 | 20 | | |
| | | — 95 | — 125 | — 300 | — 445 | — 505 | — 565 |
| „ next 5 minutes.. | | 22 | 30 | 60 | 50 | 60 | 30 |
| „ „ 5 „ .. | | 13 | 15 | 25 | 15 | 15 | 5 |
| „ „ 15 „ .. | | 25 | 35 | 27 | 20 | 25 | 25 |
| „ „ 15 „ .. | | 15 | 10 | 13 | 15 | 15 | 15 |
| „ „ 30 „ .. | | 10 | 10 | 10 | 10 | 25 | 5 |
| Duration of heating ..... | 2 hours | 75 minutes | 75 minutes | 75 minutes | 75 minutes | 75 minutes | 75 minutes |
| Total gas per gramme ash-free, dry coal .... ..... | 29·2 c.c. | 99 c.c. | 134 c.c. | 218 c.c. | 268 c.c. | 305 c.c. | 327 c.c. |
| Tarry matter per cent. | 9·05 | 13·66 | 14·8 | 13·50 | 12·25 | 10·4 | 9·0 |
| Total volatile matter per cent. | 18·79 | 28·37 | 32·33 | 36·30 | 38·05 | 38·30 | 38·83 |
| Gas analysis:— | | | | | | | |
| Benzene . | 6·20 | 6·60 | 5·40 | 4·65 | 4·40 | 3·65 | 3·00 |
| Carbon dioxide ..... | 3·60 | 3·50 | 1·95 | 1·70 | 1·90 | 1·65 | 1·70 |
| Acetylene ..... | ·35 | Not estimated | Not estimated | Not estimated | Not estimated | ·50 | *Nil* |
| Ethylene .. .. | 1·65 | 1·80 | 1·50 | ·90 | 1·40 | 1·65 | 1·85 |
| Carbon monoxide . | 6·45 | 7·10 | 9·80 | 11·85 | 13·65 | 15·10 | 15·85 |
| Hydrogen . . | 16·60 | 26·60 | 39·90 | 48·55 | 55·70 | 56·40 | 56·65 |
| Methane . . . | 37·55 | 35·20 | 29·60 | 26·10 | 16·95 | 17·55 | 17·60 |
| *Ethane . . . . | 27·60 | 19·20 | 11·90 | 6·25 | 6·00 | 3·55 | 3·40 |
| Remarks ..... | The condensible products were light coloured and consisted more of oil than of tar. The gas came off very slowly, taking about 15 minutes to fill the retort at atmospheric pressure. | The retort took about 3 minutes to fill at atmospheric pressure. | The coke had a black colour and smelled of tar. | The coke had a black colour and smelled of tar. | The coke left was white and lustrous, free from any smell of tar. There was a deposit of "methane-carbon" on the sides of the platinum boat. This deposit—due to the decomposition of methane by heat—is easily recognisable by its appearance as a thin film with a metallic lustre. | Coke, white and lustrous and free from any smell of tar. "Methane-carbon" deposited on boat. | Coke, white and lustrous and free from any smell of tar. "Methane-carbon" deposited on boat and sides of retort. |

* Including all higher homologues calculated as $C_2H_6$.

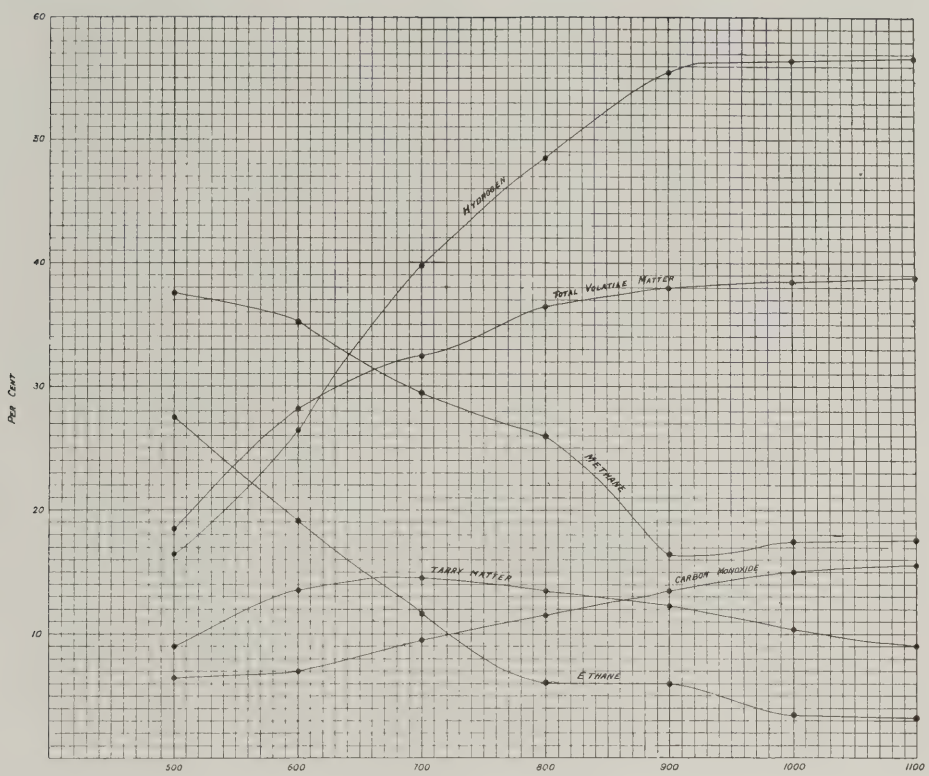


Fig. 77.—Curve showing Changes in percentage of the Principal Constituents of the gases evolved at different temperatures of distillation.

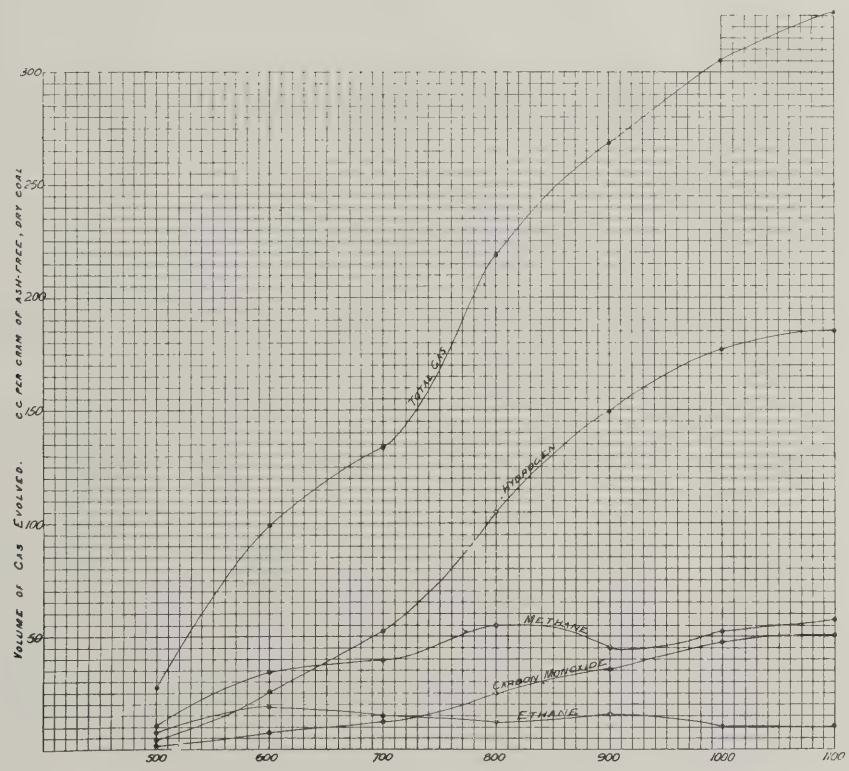


Fig. 78.—Curve showing Volumes per gramme of coal of the Principal Constituents evolved at different temperatures of distillation.

TABLE III.

VOLUMES OF DIFFERENT GASES COLLECTED AT DIFFERENT DISTILLATION TEMPERATURES.

(Cubic centimetres per gramme of ash-free, dry coal.)

| Distillation temperature. Degs. Cent. | 500 degs. | 600 degs. | 700 degs. | 800 degs. | 900 degs. | 1,000 degs. | 1,100 degs. |
|---|---|---|---|---|---|---|---|
| Carbon monoxide | 1·8 | 7·0 | 13·1 | 25·8 | 36·6 | 46·0 | 51·8 |
| Hydrogen | 4·8 | 26·3 | 53·4 | 105·8 | 149·4 | 172·0 | 185·2 |
| Methane | 11·0 | 34·8 | 39·7 | 56·9 | 45·5 | 53·5 | 57·5 |
| Ethane | 8·0 | 19·0 | 16·0 | 13·3 | 16·1 | 10·8 | 11·1 |

It would appear probable that such quantities of ethane as are found to exist in the products of the high-temperature distillations are evolved only during the initial period of slow heating-up of the coal, which necessarily takes place when the cold retort is pushed into the furnace, and that their appearance in the final products is due to their having been swept out of the retort as the rate of evolution of gas increased, and thus having escaped decomposition.

### (*b*). The Gases Evolved from Coal on First Heating.

The wide difference in composition of the gases evolved from coal at different temperatures of distillation, coupled with the fact that the rate of evolution at higher temperatures falls off so markedly after the first few minutes, suggested that it would be profitable to examine the composition of the gases driven off during the different stages of heating. To this end an apparatus was devised by means of which it was possible to collect separately the gases evolved during successive intervals of time.

The main feature of the apparatus (fig. 79) is a series of ten small gas-holders (100 cubic centimetres capacity), connected by three-way taps. These taps are so arranged that it is a simple matter to turn the stream of gas into one gas-holder after the other at a definite time.

Two of the gas-holders are shown diagrammatically in fig. 80, where it will be seen that, with the taps in the position marked 1A and 2A, any gas stream will pass into gas-holder No. 1 ; while as soon as tap No. 1 is turned into position B, gas-holder No. 1 is shut off and the gas passes at once into No. 2.

The same arrangement of platinum retort, boat, tar scrubber and electric furnace is used as in the distillations at different temperatures, and the distillations are conducted in the same manner.

The gas-holders, and all connections up to the straight tap T (fig. 80) (which is closed before the experiment), are filled with a mixture of glycerine and water, and all the taps on the gas-holders are turned into the positions 1A, 2A, 3A, &c. The retort is then exhausted through a side tap, and pushed into the electric furnace which has been previously raised to the desired temperature. As soon as the pressure of the gas evolved becomes equal to the atmospheric pressure, tap T is opened and the gas passes into gas-holder No. 1 ; it is allowed to flow for a given time and then passes into No. 2, and so on.

The whole arrangement is mounted on a wooden stand with wheels, so as to allow of the retort being introduced into the heated furnace without loss of time.

## LABORATORY EXPERIMENT A XXXI.—September 20th, 1909.

*Distillation at 900 degs. Cent.*

A dried sample of dust A (pulverised Silkstone nuts), sieved through a 240 mesh, was employed, 2 grammes being taken and intimately mixed with 3 grammes of ignited silica sand.

The temperature of the electric furnace was raised to 1,000 degs. Cent. just previous to the introduction of the retort. The retort cooled the furnace immediately to 900 degs. Cent., at which temperature it was maintained throughout the distillation. Thus the distillations collected during each time interval were evolved at a retort temperature of 900 degs. Cent.

The volumes of gas evolved, measured at 0 deg. Cent. and 760 millimetres, were as follows :—

| | | | |
|---|---|---|---|
| Distillation No. 1 | .... | During 1st 5 seconds | .... 16·05 c.c. |
| „ „ 2 | .... | „ 2nd 5 „ | .... 21·70 |
| „ „ 3 | .... | „ 3rd 5 „ | .... 25·50 |
| „ „ 4 | .... | „ 4th 5 „ | .... 30·20 |
| „ „ 5 | .... | „ 5th 5 „ | .... 34·95 |
| „ „ 6 | .... | „ 6th 5 „ | .... 32·10 |
| „ „ 7 | .... | „ 7th 5 „ | .... 32·10 |
| „ „ 8 | .... | „ next 10 „ | .... 60·45 = about 30·2 per 5 seconds |
| „ „ 9 | .... | „ „ 15 „ | .... 70·80 = about 23·6 per 5 seconds |
| „ „ 10 | .... | „ „ 30 „ | .... 56·65 = about 9·3 per 5 seconds |

The increasing quantity of gas evolved during successive time intervals up to the fifth period of 5 seconds indicates the gradual heating up of the coal inside the retort ; any difference in composition of the gases evolved during these periods must therefore be regarded as arising partly from the different temperatures at different stages and partly from the different stage of decomposition of the coal.

The analyses of the separate distillations of gas were as follows, calculated as "nitrogen-free" gas :—

| | 1. | 2. | 3. | 4. | 5. | 6. | 7. | 8. | 9. | 10. |
|---|---|---|---|---|---|---|---|---|---|---|
| Benzene | 9·45 | 7·45 | 6·85 | 6·60 | 4·80 | 4·10 | 2·45 | 1·60 | 0·20 | 0·20 |
| Carbon dioxide | 2·35 | 2·65 | 2·80 | 2·45 | 1·25 | 1·80 | 1·60 | 1·60 | 0·60 | 0·30 |
| Acetylene | 1·45 | 1·15 | 1·20 | 0·85 | 1·05 | 1·00 | 0·55 | *Nil* | 0·30 | *Nil* |
| Ethylene | 6·85 | 4·35 | 5·50 | 4·65 | 4·05 | 2·80 | 1·35 | 0·75 | 0·20 | 0·10 |
| Carbon monoxide | 12·60 | 12·10 | 12·50 | 12·40 | 11·75 | 11·95 | 11·75 | 11·25 | 10·00 | 8·85 |
| Hydrogen | 11·35 | 23·85 | 30·75 | 33·50 | 33·95 | 39·00 | 48·95 | 62·30 | 77·75 | 82·85 |
| Methane | 44·55 | 37·65 | 32·90 | 31·05 | 34·75 | 32·75 | 28·30 | 20·55 | 10·10 | 7·70 |
| Ethane | 11·40 | 10·85 | 7·55 | 8·45 | 8·40 | 6·55 | 5·05 | 2·00 | 0·80 | *Nil* |

The total number of cubic centimetres of each constituent evolved per gramme of ash-free dry coal during each time interval has been calculated as follows :—

| | 1. | 2 | 3. | 4. | 5. | 6. | 7. | 8. | 9. | 10. |
|---|---|---|---|---|---|---|---|---|---|---|
| Benzene | 0·75 | 0·82 | 0·83 | 1·00 | 0·86 | 0·66 | 0·39 | 0·50 | 0·07 | 0·06 |
| Carbon dioxide | 0·18 | 0·28 | 0·33 | 0·40 | 0·22 | 0·30 | 0·26 | 0·50 | 0·22 | 0·09 |
| Acetylene | 0·11 | 0·12 | 0·14 | 0·12 | 0·18 | 0·15 | 0·09 | *Nil* | 0·11 | *Nil* |
| Ethylene | 0·54 | 0·45 | 0·67 | 0·71 | 0·73 | 0·45 | 0·22 | 0·22 | 0·07 | 0·03 |
| Carbon monoxide | 0·99 | 1·35 | 1·54 | 1·87 | 2·10 | 1·94 | 1·91 | 3·44 | 3·59 | 2·51 |
| Hydrogen | 0·90 | 2·62 | 3·78 | 5·10 | 6·13 | 6·41 | 8·04 | 19·08 | 27·94 | 23·51 |
| Methane | 3·53 | 4·18 | 5·10 | 4·73 | 6·23 | 5·35 | 4·63 | 6·33 | 3·64 | 2·19 |
| Ethane | 0·90 | 1·20 | 0·94 | 1·28 | 1·59 | 1·14 | 0·82 | 0·61 | 0·28 | *Nil* |

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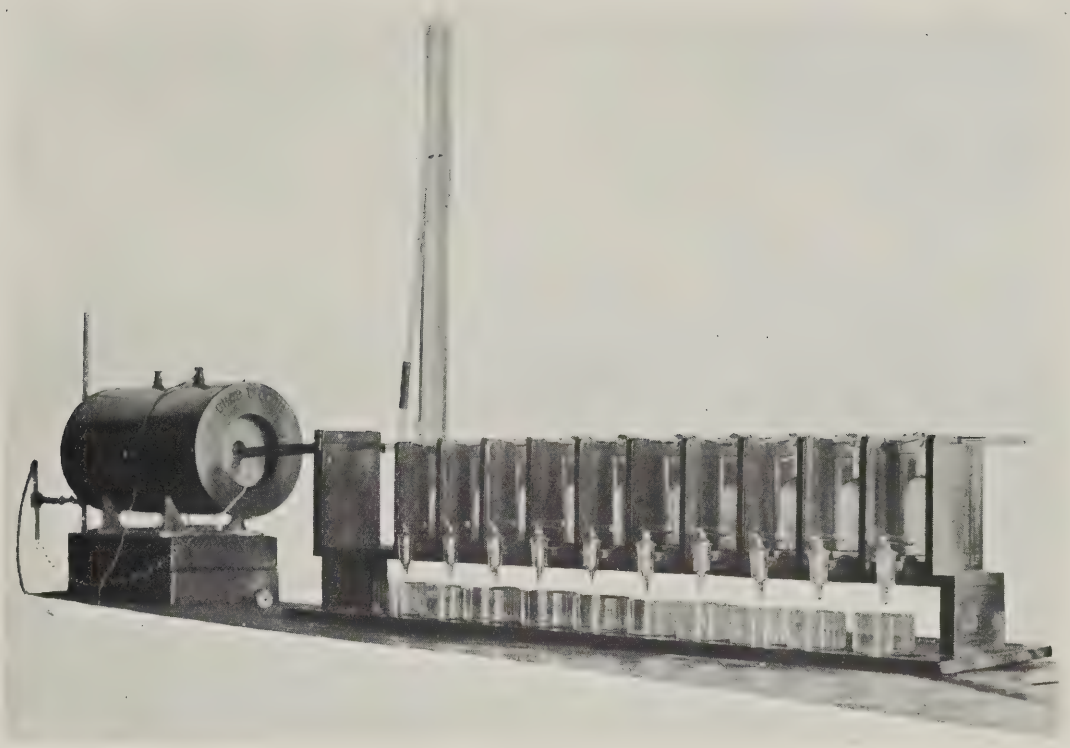

Fig. 79.—General arrangement of Apparatus for Collecting Samples of Gas during successive intervals of time; showing series of Gas-holders.

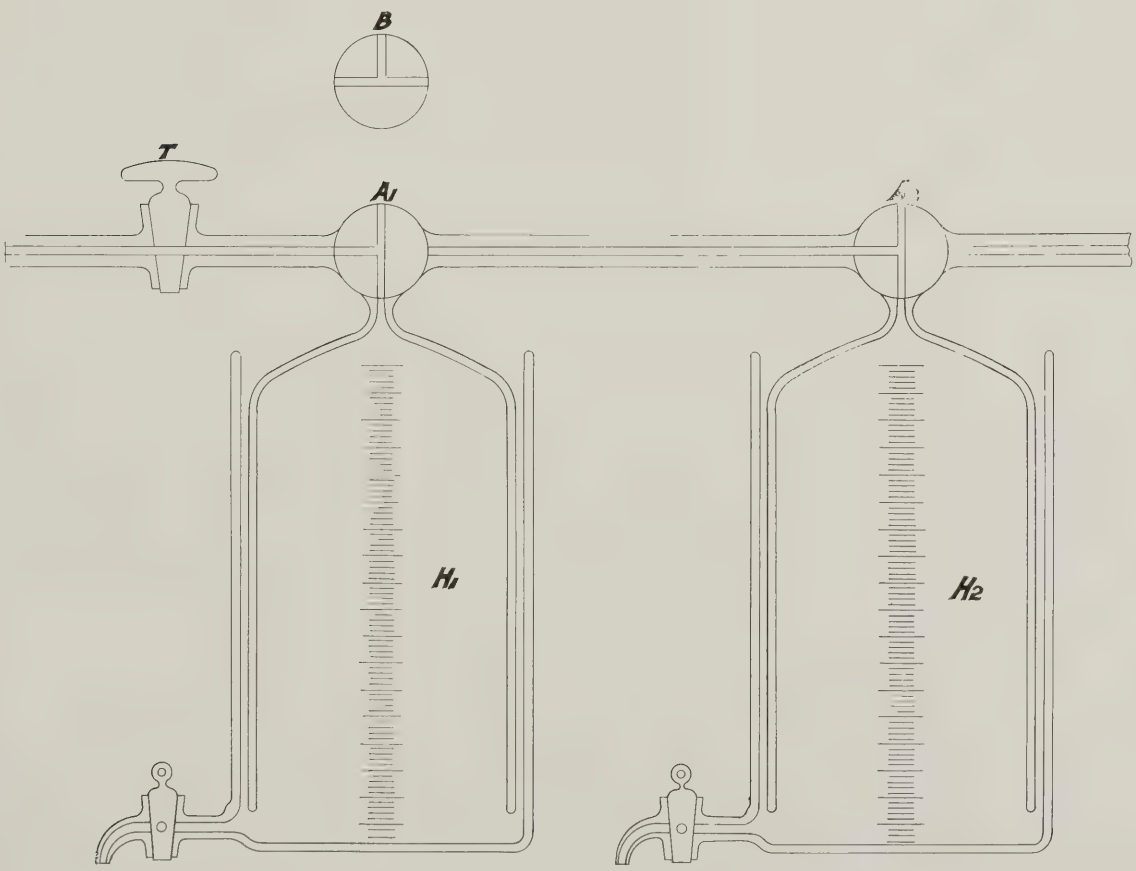


Fig. 80.—Arrangement of Gas-holders for Collecting Samples during successive intervals of time.

Fig. 81.—Curve showing Volumes of each of the Principal Constituents evolved during successive intervals of time at a distillation temperature of 900 degs. C.

From the figures in the latter table the curve shown in fig. 81 has been plotted. This curve shows the rate of evolution of the chief constituent gases—hydrogen, methane, ethane and carbon monoxide—and indicates very clearly that the hydrocarbons, methane and ethane are the primary (gaseous) decomposition products of the coal at the temperature of distillation employed, whereas the main bulk of the hydrogen is a secondary product. For the evolution of the ethane ceases entirely after the first 60 seconds, while the rate of evolution of methane has greatly diminished: the hydrogen, on the other hand, continues to be evolved fairly rapidly and soon overtakes the rate of evolution of methane.

Experiments at a lower temperature of distillation show somewhat different characteristics. As an example the following may be quoted :—

### LABORATORY EXPERIMENT A XLI.—February 4th, 1910.

*Distillation at 625 degs. Cent.*

Dust A, through 240 mesh. Two grammes mixed with 3 grammes of ignited silica sand.

The apparatus took two minutes to fill at atmospheric pressure, after which ten distillations of the gas evolved were collected during successive periods of five seconds each.

The rate of evolution of gas was practically uniform, about 2·5 c.c. being collected during each period of five seconds.

The analyses of these distillations were as follow, calculated as "nitrogen-free gas" :—

| | 1. | 2. | 3. | 4. | 5. | 6. | 7. | 8. | 9. | 10. |
|---|---|---|---|---|---|---|---|---|---|---|
| Ammonia | 1·00 | 4·35 | 5·50 | 3·80 | 4·50 | 3·35 | 5·20 | 3·45 | 3·75 | 2·75 |
| Benzene | 9·25 | 11·00 | 8·90 | 9·45 | 8·15 | 7·60 | 7·65 | 8·35 | 6·60 | 7·75 |
| Carbon dioxide | 4·65 | 2·15 | 2·15 | 2·90 | 2·45 | 2·15 | 1·95 | 3·05 | 2·65 | 0·40 |
| Acetylene | 0·25 | 1·55 | 1·15 | 0·70 | 2·15 | 0·60 | 1·00 | 0·20 | 0·05 | 0·85 |
| Ethylene | 2·65 | 2·25 | 3·85 | 3·35 | 2·30 | 3·00 | 1·55 | 1·35 | 2·50 | 1·05 |
| Carbon monoxide | 8·80 | 9·45 | 7·95 | 8·40 | 8·50 | 8·45 | 6·80 | 7·45 | 7·15 | 9·25 |
| Hydrogen | 3·60 | 2·15 | 2·30 | 3·35 | 2·80 | 3·45 | 2·60 | 1·40 | 1·75 | *nil* |
| Methane | 42·90 | 39·05 | 44·15 | 43·10 | 47·60 | 52·35 | 56·00 | 57·35 | 62·65 | 61·85 |
| Ethane | 26·85 | 28·10 | 24·05 | 24·85 | 21·55 | 19·00 | 17·15 | 17·40 | 12·90 | 16·30 |

It will be seen that very little hydrogen was present in any of the distillations : none at all could be detected in No. 10.

The principal constituents are ethane and methane, while the latter increases gradually at the expense of the former * as the heating proceeds.

Many such distillations have been made, both at different temperatures and with different samples of coal, and the above are merely given as examples to show the lines upon which the work is proceeding. The composition of the gases given off during the first few seconds, by samples from different seams, varies very greatly. In particular, some coals give off greater quantities of ethane than others. Anthracite coal evolves practically no ethane.

Since it is the gases evolved during the first stage of heating that are of most importance having regard to any influence they may have on the propagation of coal

* Ethylene is probably formed as an intermediate product by the decomposition of ethane. *See* "The Thermal Decomposition of Hydrocarbons." W. A. Bone and H. F. Coward. *J.C.S.*,1909.

dust explosions, or on the relative inflammability of the dust, it is hoped, as already stated, that work of this kind, when completed, may enable a comparison of the explosive nature of different coal dusts to be made.

### (*c.*) The Momentary Heating of Coal Dust.

In order to obtain further information as to what part, if any, the gases that can be distilled from coal play during the propagation of a coal dust explosion, an experimental method has been devised of simulating in the laboratory the heating effect that presumably must take place during an explosion prior to combustion of the dust: that is, momentary heating to a high temperature.

It seems most probable that the actual explosion is propagated practically entirely by the combustion of the dust as a whole, for the rapidity with which the

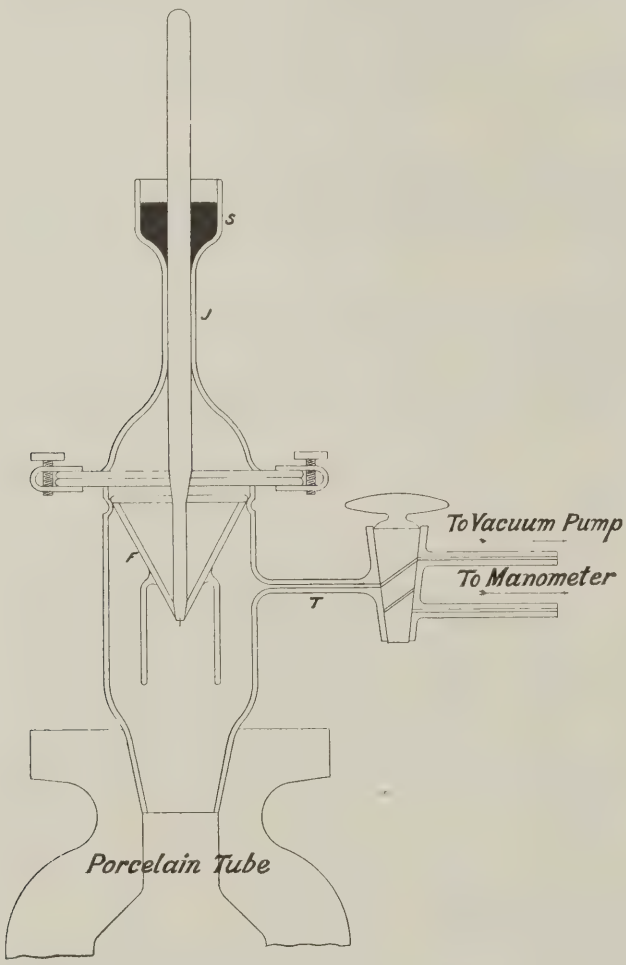


Fig 83.—Arrangement for dropping Coal Dust through a Heated Atmosphere.

explosion travels is hardly compatible with the notion that distillation of gas must first take place, and that it is the combustion of that gas which is chiefly responsible for the explosive effects; such a distillation must take an appreciable time and absorbs heat. It must be remembered, however, that in the same manner as in a gaseous explosion, each layer of dust and air mixture is raised in temperature, by heat produced by the burning of the layer just behind it, before it is actually burnt; that is to say, the dust has to be raised to its "ignition point" before rapid combustion can take place. Should the time that this occupies be comparatively long, say $\frac{1}{100}$ second or more, there might be time for a certain amount of distillation to take place, and for the inflammable gases evolved to add their effect to the

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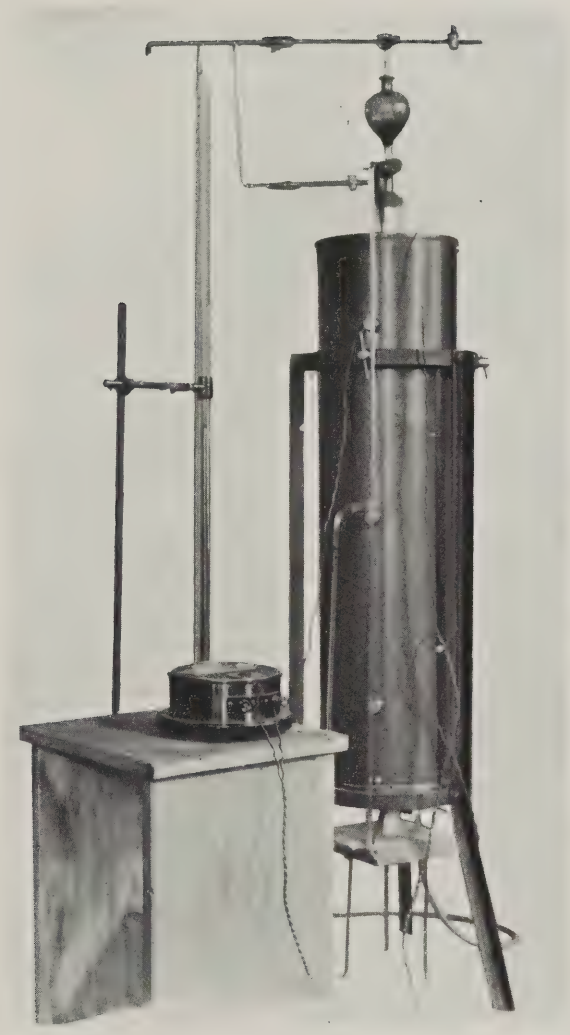


Fig. 82.—The Momentary Heating of Coal Dust.
No. 1 Furnace.

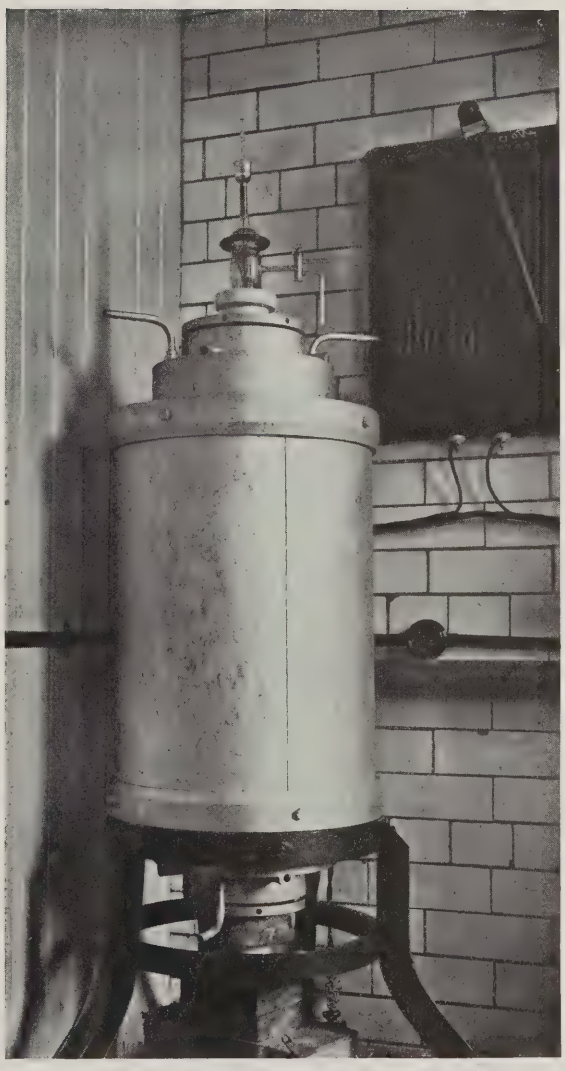


Fig. 84.—The Momentary Heating of Coal Dust.
No. 2 Furnace.

explosion. Distillation will, moreover, certainly take place after the explosion has passed, owing to the heated products of combustion surrounding excess of unburnt coal dust. Any supply of fresh air drawn from branch roads in the wake of the main explosion would mix with the distilled gases, and, if they are still at a sufficiently high temperature, cause a secondary explosion.

It is therefore important to try to determine the extent to which distillation can take place in a very short interval of time, and to test whether dusts from different seams of coal and of different degrees of fineness show any marked differences in behaviour under the same treatment.

In order to obtain momentary heating of coal dust, the apparatus shown in fig. 82 has been employed. The dust is caused to drop vertically through a heated atmosphere, the length of time during which the dust is heated being calculated from the time taken for it to fall through the heated zone.

The "heated atmosphere" employed could not, of course, be air, since it was necessary to avoid combustion of the dust. The apparatus had therefore to be filled with an inert gas, and a means of allowing the dust to fall in a fine stream had to be arranged which would avoid the possibility of air being introduced accidentally into the apparatus.

The arrangement for dropping the dust that was finally adopted is shown diagrammatically in fig. 83. The dust is weighed into the glass funnel F, a fine hole at the bottom of which is closed by a glass rod with its end ground conical and fitted with a platinum point. The rod passes through the top of the apparatus through a parallel ground glass joint J protected by a mercury seal S. The whole arrangement fits, by means of a ground joint, into a porcelain tube placed vertically in an electric resistance furnace (fig. 82) ; the winding of this furnace is so arranged that the length of the heated zone employed can be either 30 or 60 centimetres. By means of a side tube T the apparatus can be exhausted of air and filled with an inert gas, while a mercury manometer serves to show any change in pressure that may occur when the dust is dropped. The lower end of the porcelain tube is closed by a small glass cup which serves to catch the dust after it has fallen through the heated zone.

The first series of experiments have been made using a tube 1 in. in diameter through which the dust is dropped, carbon dioxide being employed as the best substitute for an "inert" atmosphere. This gas can afterwards be easily removed by absorption by caustic potash solution, and any residue of distilled gases can be analysed with greater accuracy than would be the case if nitrogen were employed. Its use has incidentally shown that the rate at which the reaction

$$CO_2 + C = 2CO$$

proceeds must have an important bearing on the presence of carbon monoxide in the afterdamp of a coal dust explosion.

## LABORATORY EXPERIMENT A 4.—March 16th, 1909.

This experiment was made with Silkstone coal that had been crushed so as to pass through a 10 mesh and remain on a 30 mesh sieve, such a comparatively large size of dust* being used in order that the length of time taken for the particles to

* The particles averaged 2 mm. cube.

fall through the heated zone might be correspondingly short, and to avoid the projection of small particles on to the heated sides of the tube.

One gramme of coal taken, well dried and freed from all fine dust.
Temperature = 1,000 degs. Cent.
Length of heated zone = 60 cm.
Atmosphere = carbon dioxide, previously dried over strong sulphuric acid.

*Result of Experiment.*

| | | |
|---|---|---|
| Original pressure in apparatus | = 756 | mm. |
| Pressure after dropping dust | = 802 | „ |
| Increase | = 46 | „ |

The gases were withdrawn from the apparatus by a mercury vacuum pump and passed through caustic potash solution, the carbon dioxide being thus removed. The volume of the gas remaining unabsorbed was 17 cubic centimetres and it contained :—

| | |
|---|---|
| Ethylene | 0·55 per cent. of "nitrogen-free gas" |
| Carbon monoxide | 90·50 |
| Hydrogen | 7·50 |
| Methane | 1·45 |

The carbon monoxide arises from the interaction of the carbon of the coal with the carbon dioxide "atmosphere."* In addition to this it appears that a small quantity of inflammable gas has been distilled from the coal during its passage through the heated zone. The length of time that each particle of the coal was heated was a little over $\frac{1}{6}$ second,† while the number of particles in a gramme amounts to about 1,600.

Although great care is taken in these experiments that the furnace is perfectly vertical and that the dust falls centrally without coming into contact with the heated sides of the tube, it is desirable, before making any definite statement as to the extent to which distillation can take place in so short a time as $\frac{1}{100}$ second, to experiment with a larger tube ; for this purpose the furnace shown in fig. 84 has been designed capable of taking a porcelain tube 4 in. in diameter.

## OTHER LABORATORY RESEARCHES.

In addition to the work that has been described in the foregoing pages, and which deals essentially with the behaviour of coal on heating, there are three other branches of the enquiry that have received attention, namely :—

(1.) The action of oxygen (air) upon incandescent carbon.
(2.) The weathering of coal.
(3.) The influence of the presence of incombustible dust upon gaseous explosions.

In each case the work is of such a nature as to render it inadvisable at present to do more than state the object aimed at, for, although good progress has been made, the results obtained, unlike those in connection with the heat treatment of coal, require to be studied as a whole, and individual experiments have very little significance.

* A previous series of experiments to test whether carbon dioxide could be regarded as an "inert" atmosphere was made, using wood charcoal instead of coal ; 15 cubic centimetres of carbon monoxide remained after absorbing all the carbon dioxide.

† The particles are assumed to fall through the heated zone with the velocity acquired after falling 1 ft. from rest, and with the acceleration due to gravity. Stokes' formula does not apply to such heavy particles.

### (1.) The Action of Oxygen (Air) upon Incandescent Carbon.

There is still considerable difference of opinion amongst chemists as to the mode of combustion of carbon. The commonly accepted view is that carbon burns directly to carbon dioxide, which in contact with an excess of incandescent carbon is immediately reduced to carbon monoxide, thus :—

$$(a)\ C + O_2 = CO_2, \text{ and}$$
$$(b)\ CO_2 + C = 2CO.$$

This view is, however, unsupported by any *conclusive* evidence, and is difficult to reconcile with H. B. Baker's* classical experiments on the combustion of solid carbon. Moreover, the work of H. B. Dixon† on the rates of explosion of cyanogen and oxygen, corresponding to $C_2N_2 + O_2$ and $C_2N_2 + 2O_2$ respectively, leaves no room for doubt that *gaseous* carbon burns in two well-defined stages—viz., (1) *directly* to carbon monoxide,

$$C_2N_2 + O_2 = 2CO + N_2,$$

and (2) with a sufficient supply of oxygen the carbon monoxide is subsequently burnt to carbon dioxide,

$$2CO + O_2 = 2CO_2.$$

Taking the whole of the known facts into consideration, it would appear that the balance of evidence is in favour of the view that *solid* carbon also burns directly to carbon monoxide, and that carbon dioxide is only formed by the secondary combustion of the monoxide. Continental chemists, however, have arrived at an opposite conclusion from the same evidence.

In order to explain completely the results of analyses of the afterdamp obtained from coal dust explosions, it is of the utmost importance that this question should be definitely settled. An estimation of the rate at which carbon dioxide can be reduced to carbon monoxide by excess of carbon at different temperatures, and the rate at which carbon monoxide combines with oxygen to form carbon dioxide, form part of the same problem.

### (2.) The Weathering of Coal.

A great deal of research has been carried out in the past regarding the effect of weathering upon coal with the main object of explaining the difference produced in its coking properties.

In connection with coal dust explosions, W. N. and J. B. Atkinson have observed‡ that the coal dust collecting on the higher parts of haulage roads ("upper dust") appears to undergo some change and *become more readily combustible than fresh coal dust.* They found that upper dust, collected from dry collieries in the North of England, had the property of burning *en masse*—that is, if a flame was applied so as to heat a small portion of it to redness, combustion gradually spread through the whole mass. They further state as their opinion that upper dust would appear to have undergone some chemical or physical change, and that absorption of oxygen from the air may possibly have taken place.

The latter assumption has proved to be correct; and also, that the effect of passing a slow stream of air through finely divided coal dust is, in some cases, to raise the temperature of the coal above that of the surrounding atmosphere.

* *Journal* of the Chemical Society, 1885, Vol. xlv., p. 349; also *Phil. Trans.* of Royal Society, 1888, Vol. clxxix. A.

† *Journal* of the Chemical Society, 1896, Vol. lxix; 1899, Vol. lxxv.

‡ "Explosions in Coal Mines," page 21.

The problem is being attacked along two lines; first, the changes occurring in the composition of the coal, and, second, the change in composition of the air after passing over the coal, are being examined.*

## (3.)—The Influence of the Presence of Incombustible Dust on Gaseous Explosions.

Sir Frederick Abel,† in the course of his enquiry into the cause of the Seaham Colliery explosion in 1880, made experiments which seemed to show that "perfectly "non-combustible powders, which are also not susceptible to any change when "exposed to the action of flame, have the property of bringing about the ignition of "an otherwise uninflammable mixture of firedamp and air."

Doubt has been cast upon Abel's results on the ground that he did not obtain perfect mixture of gas and air, and, although later experiments by Mallard and Le Chatelier‡ point to the same conclusion, it seems desirable that the work should be repeated and amplified having regard to the use of stone dust as a possible preventive of coal dust explosions.

* Incidentally, it is hoped that from the manner in which the experiments are being made they will yield information as to the cause of spontaneous combustion of coal and of "gob-fires."

† "Report on the Results of Experiments made with Samples of Dust Collected at Seaham Colliery," 1880.

‡ *Annales des Mines*, 1882.

## CHAPTER IX.

# MICROSCOPICAL INVESTIGATIONS.

CHAPTER IX.

## MICROSCOPICAL INVESTIGATIONS.

The Committee, having before them the evidence which had been given by Mr. Garforth before the Royal Commission on Coal Dust in Mines, considered that this Report would not be complete without an account of the examination by means of the microscope of the material gathered after an explosion. Having also heard that Mr. Garforth and Mr. Crowther had, since 1887, been conducting further investigations, they requested that an account of the results obtained should be included in this Report.

It was suggested by Mr. Garforth in 1887 that the microscope might afford information regarding coal dust explosions that was outside the range of chemical analysis. In evidence before the Royal Commission in 1891 he was able to give the results of the microscopical examination of the dust obtained from the Altofts Silkstone Pit after the explosion in 1886, and stated :—

> " That coal dust in an explosion may be only partly burned, or be burned to
> " coke or may escape the flame ; that the same kind of fracture is found in the
> " smaller as in the larger pieces ; and that fossil plant spores may be present."

Drawings of some of the objects observed were submitted to the Commission and reproduced in Appendix XII., *d*, *e*, *f*, *g*, of their Report. These drawings are shown on a smaller scale on Plates A and B of this Report.

The material collected from the underground workings after the Altofts Explosion has fortunately been preserved, so that it has been possible to compare the dust collected after the explosions in the gallery with that remaining after an actual colliery disaster, the coal in both cases being from the same seam (Silkstone). In this way an explanation has been forthcoming of the occurrence of certain bodies regarding which the earlier investigations did not afford complete information.

*The Microscope.*—Microscopes of the latest design have been employed.* (Plate C, figs. 1 and 2.) The coarse adjustment is made by a special spiral rack and pinion, and the final focussing by a fine screw adjustment. (Plate C, fig. 2.)

The rectilinear motions by which objects are brought into the field of view of the microscope are effected by the movement of two milled heads fixed on the same side of a Swift's patent mechanical stage. (Plate C, fig. 2.) Lewis Wright's finder is fitted to the stage. This consists of a series of numbered lines ruled at right angles to each other. When any special object is seen, its position in the field of view is marked for future reference by recording on the slide the position of its right-hand upper angle in the engraved area. The horizontal lines of the index read from 0 to 25, the vertical lines from 25 to 50. An object registered, for example, as $\frac{28}{16}$ is thus readily found again. (Plate C, fig. 2.)

* The monocular microscopes were made by Messrs. James Swift and Son, London, and are of "The Discovery" pattern.

Each microscope has a sub-stage fitted with a combined Abbe condenser and iris diaphragm ; or the polariser of a polarising apparatus can be substituted.

The size of the objects can be measured by means of a stage micrometer ruled in divisions of $\frac{1}{100}$ and $\frac{1}{1,000}$ in. ; and by the insertion, in a low-power eye-piece, of a micrometer ruled in squares of $\frac{1}{100}$ in. The size of the object is calculated from the number of squares or parts of a square that it occupies on the micrometer in the eye-piece.

Explosion material is more or less opaque, and difficult to manipulate for microscopical examination. It may be examined by transmitted light, the intensity of which may be increased by the aid of an Abbe condenser, or by reflected light ; sometimes a Swift's parabolic reflector, or a Beck's vertical illuminator, was used.

Sanderson's cameras were used for the ordinary photographing of cokes and dust in the gallery ; Swift's horizontal photo-micrographic camera for the microscopical enlargements. (Plate D, figs. 1 and 2.)

It has been ascertained by direct measurement that particles $\frac{1}{40,000}$ in. in diameter,* recognisable as coal dust, float in the air of the haulage ways.

The use of the microscope is, of course, restricted to the study of the appearance of bodies, but it is possible, with practice, to obtain such information as will enable a definite statement to be made regarding the nature of a body from its appearance. In this way it is believed that valuable data regarding coal dust explosions can be obtained and kept for future reference ; for one of the great advantages of microscropical work is that the objects can be preserved as permanent records.

The micro-slides, over 300 in number, of the material examined during the course of this investigation are deposited in the Leeds Museum for use for reference by those interested in the subject.

*The Action of Heat upon Coal Dust.*—Before describing the material left after an explosion, it is of value to study the action of heat upon coal dust and the nature of the products as they appear under the microscope. In this way the separate products of the action of heat upon coal dust can afterwards be recognised among "explosion dust" by their appearance.

On gently heating fine Silkstone coal dust, the particles cohere to form small masses. It is interesting to note that the frictional heat of the pulveriser used to prepare the dust is sufficient to induce the coherence of some of the particles. (Plate E, fig. 2.)

On further heating, the sharp outlines of the separate particles of dust disappear and a certain amount of tar is distilled. Parts of the coal dust may become covered with bubbles of tar (Plate F, figs. 2 and 3). The tarry products may be recognised by their colour, by the lines of flow and by the presence of dust and minute bubbles. (Plate H, fig. 1.)

The further action of heat upon tar produces pitch. Pitch appears as dead black in thick sections : in thin films it is transparent, and then has the same appearance as tar, but is of a deeper colour. The fragments of pitch are usually fenestrated, containing windowlike openings bridged by curved bars. (Plates G and H, fig. 3.)

* It is possible to observe bodies of an even smaller size ; thus, on the flint frustules of a common plant known as a diatom, markings $\frac{1}{90,000}$ in. apart can be seen.

All these products of the action of heat upon coal dust can be recognised in samples obtained after a gallery explosion. The shelves and floor after an explosion that has not been attended by much violence are covered with a fragile spongy layer of coke. (Plate F, fig. 1.)

The residue left after the complete combustion of the coal dust is mineral ash. That obtained from Silkstone coal dust heated upon a piece of platinum foil appears of a salmon colour due to the intermingling of red oxide of iron with white granules of silica, many of which are only $\frac{1}{30,000}$ in. in diameter. (Plate I, fig. 1, and Plate J, figs. 1, 2, and 3.)

In addition to these familiar products of the action of heat upon coal, the dust collected after an explosion contains two different types of bodies of characteristic appearance.

Bodies of the first type appear as hollow spheres made up of grains of cohering coal dust. Some of the spheres have openings as if parts had been torn away. (Plate A, fig. 3, and Plate K, figs. 1 and 2). Each coal dust particle in these spheres is distinctly recognisable, and it is to them that the granular appearance is due. When highly magnified the particles appear as " cobbles " of coal cemented by a mortar of tar.

Those of the second type, which do not appear to have been elsewhere described, are also hollow spheres, but are sepia coloured and very fragile. They vary in diameter from $\frac{1}{250}$ to $\frac{1}{1,000}$ in. (Plate L, fig. 3, and Plate M, figs. 1-5).

It is proposed to name the former " carbospheres," since they are practically pure coal ; and the latter " microspheres " owing to their minuteness.

Carbospheres and microspheres have been found not only among the dust remaining after the Altofts Explosion of 1886, but also in such samples as have been collected after the gallery explosions. They are therefore typical of " explosion dust."

Experiments were therefore made to see whether such bodies could be prepared artificially, and the conditions under which they were most readily formed.

Coal dust particles which had been fed into a blow-pipe flame and projected but a short distance by the flame, were found to have become rounded. Many particles had cohered and contained tar. There were also carbospheres present, from which some of the particles had been displaced, leaving ragged fringes of tar.

The particles projected by the flame to a further distance had also formed carbospheres, and pieces of fenestrated pitch could be detected. There were also microspheres and very fine dust (micro-dust). In general appearance the material was similar to that gathered after the Altofts Explosion.

Further experiments were then made, in which the blow-pipe flame was directed through a glass tube that had been previously heated.

Granular spherical aggregations of coal dust particles (carbospheres) were found among the dust that dropped nearest the flame. They were similar in form and size to those found among mine explosion dust.

Selections of the material projected to a still greater distance by the flame were found to contain fenestrated fragments of pitch, carbospheres and microspheres. (Plate K, figs. 3 and 4.)

These experiments, therefore, confirmed those made with the open blow-pipe flame, and also showed that the increased and sustained heat, due to the use of the

protecting glass tube, allowed of a more extensive distillation of tar from the coal and of the formation of a larger number of carbospheres.

A common feature of the dust left after an explosion is the occurrence of arrow-headed particles of pitch. On the assumption that such particles were sections of larger fragments of pitch, an examination was made of the action of heat upon tar and pitch, and of the appearance of cooled portions of the latter.

When tar was pressed between a cover-glass and a micro-slip water was expressed. The movement of the water detached portions of the tar and both water and tar were seen to contain innumerable minute specks of black dust. This dust is probably carbon in the form of smoke. (Plate G, figs. 1 and 2, and Plate H, fig. 1).

On heating the tar on the glass slip until all the volatile oils had been driven off, a film of pitch was formed which, on cooling, cracked into triangular and hexagonal fragments similar in appearance to those found among the dust after an explosion. (Plate I, fig. 3.)

Plant spores were also found among the dust collected after the Altofts Explosion. Thus in Plate A, fig. 1, is shown a megaspore, and in fig. 3 microspores. Plant tissue (Plate N, figs. 1, 2, 3).

Many examinations have been made of the dust remaining in the gallery after an explosion.

A sample taken from a prop after an experiment on April 24, 1907,* showed the formation of tar and of pitch which, on cooling, had broken into curved fragments. Across many of the fenestrations of the pitch were stretched films of tar. (Plate L, fig. 2.)

In order to obtain samples of the dust ejected from the downcast end of the gallery during an explosion, a number of short posts were driven into the ground in front of the downcast end at distances of 30 ft. apart and almost directly in the line of fire. On the ends of the posts, at a height of 18 in. above the ground, metal clips were fixed holding slips of glass smeared with a solution of fish glue in dilute acid to cause the dust to adhere.

A sample obtained in this manner after Experiment No. 9†, from a post 60 ft. in front of the downcast end, contained splinters of unburned coal dust, particles of quartz, fenestrated fragments of pitchy matter, microspheres and carbospheres.

The sample showed all the characteristics of mine explosion dust, and was the first evidence obtained of the similarity between the dust remaining after the 1886 mine disaster and that obtained from a gallery explosion. (Plate L, fig. 3.)

Two samples were obtained after Experiment No. 10.† The first, from a post 30 ft. in front of the downcast end, contained microspheres, carbospheres, quartz particles and micro-dust. The quartz particles were identical with those ordinarily met with in binds, clays and sands, and contained natural gas inclusions.

The second, 30 ft. further away, was of a similar character, but the particles of coal dust were of a smaller size. There were, in addition, particles of fossil plant tissue of similar structure to the scalariform vessels of Stigmaria.

* This experiment was made before the B.C.D. experiments were begun. The gallery employed was 130 ft. long and $7\frac{1}{2}$ ft. in diameter.

† The flame of the explosions in Experiments Nos. 9, 10 and 12 shot out beyond the downcast end 90, 180 and 150 feet respectively.

MICROSCOPICAL ILLUSTRATIONS.

# ALTOFTS EXPLOSION
(1886).

Plate A

## EXPLODED COAL DUST.

APPENDIX XII *(d) (e)*

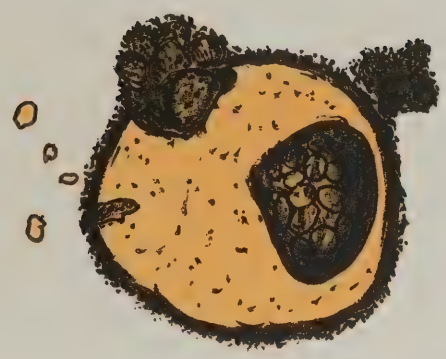


FIG. 1. *(d).*

*Coal dust particles and the presence of spores of cryptogams.*

FIG. 2. *(e).*

*In this particle of Charred Coal the black portion is supposed to indicate the manner in which the flame cokes the organic particle. The holes have been probably caused by escaping gases.*

*Scale for Fig. 1 & 3*

*One ten-thousandth part of an Inch*

FIG. 3. *(d).*

*The megaspore and microspores of some cryptogamous plants partly charred.*

APPENDIX XII *(f)*

COKE.

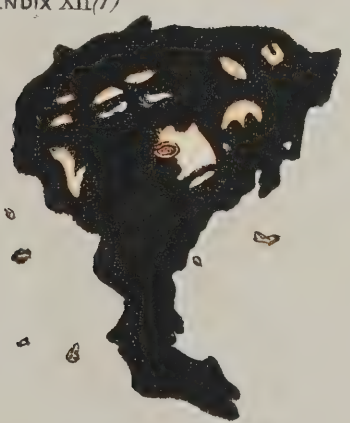


FIG. 4.

*Vascular Structure shewing woody origin. The spore of some cryptogam in orifice is accidental. The surrounding particles are Coal dust.*

FIG. 5.

*Particle of Coke with Coal dust overlying. The appearance of the outside edge is probably due to escaping gases.*

*Scale for Fig 4 & 5*

*One ten-thousandth part of an Inch*

*To Illustrate*
*Mr W.E. Garforth's Evidence Royal Commission Coal Dust in Mines, July 1891.*

# ALTOFTS EXPLOSION
(1886).

Plate B

## COKE.

APPENDIX XII(f)

FIG. 6.

*Scale for Fig 6.*
*One thousandth part of an Inch*

*The presence of organic tissue is shewn by Vascular Structure. In this particle it is supposed the heat has been so intense that the Coked Coal has been vitrified.*

## DIRT DUST.

APPENDIX XII(g)

FIG. 7.

*Dirt Dust with Coal particles embedded in a matrix of inorganic matter.*

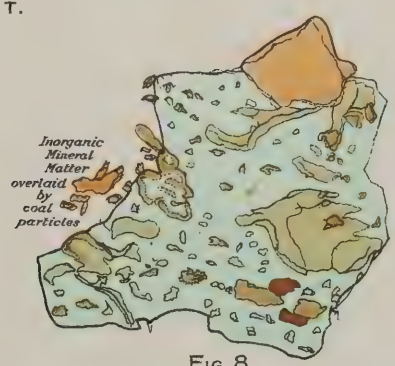



FIG. 8.

*Dirt Dust with Coal particles embedded in a matrix of inorganic matter.*

*Scale for Figs 7, 8 & 9.*
*One ten-thousandth part of an Inch.*

FIG. 9.

*Coal particles embedded in a matrix of inorganic matter with Coke particles in close proximity.*

*To Illustrate*
*Mr W.E. Garforth's Evidence Royal Commission Coal Dust in Mines, July 1891.*

PLATE C.

Fig. 1.—"THE DISCOVERY" MICROSCOPES.—The one on the left is fitted with polarising apparatus, the one on the right with an Abbe condenser.

Fig. 2.—WORKING PARTS OF MICROSCOPE.—1, Stage; 2, Lewis Wright's finder; 3, Swift's mechanical stage which runs up and across Stage 1; 4, Milled heads of screws giving rectilinear motion to mechanical stage; 5, Milled head of diagonal rack and pinion, giving coarse adjustment when focussing objects; 6, Milled head for fine adjustment; 7, Objectives on double nose-piece; 8, Mirror for transmitting light; 9, Head of screw for adjusting condenser in sub-stage; 10, Tripod stand; 11, Optical tube; 12, Abbe condenser carried on sub-stage; 13, Double nose-piece; 14, Analyser; 15, Polariser.

The Coloured Drawings of the Microscopical Objects were made by Miss Violet M. Crowther, Leeds Museum, directly through the microscope and by means of a specially designed camera lucida.

The Reproductions from half-tone blocks and the Lithography in colours of the Microscopical illustrations have been executed by Messrs. Chorley & Pickersgill, Leeds.

MICROSCOPES.

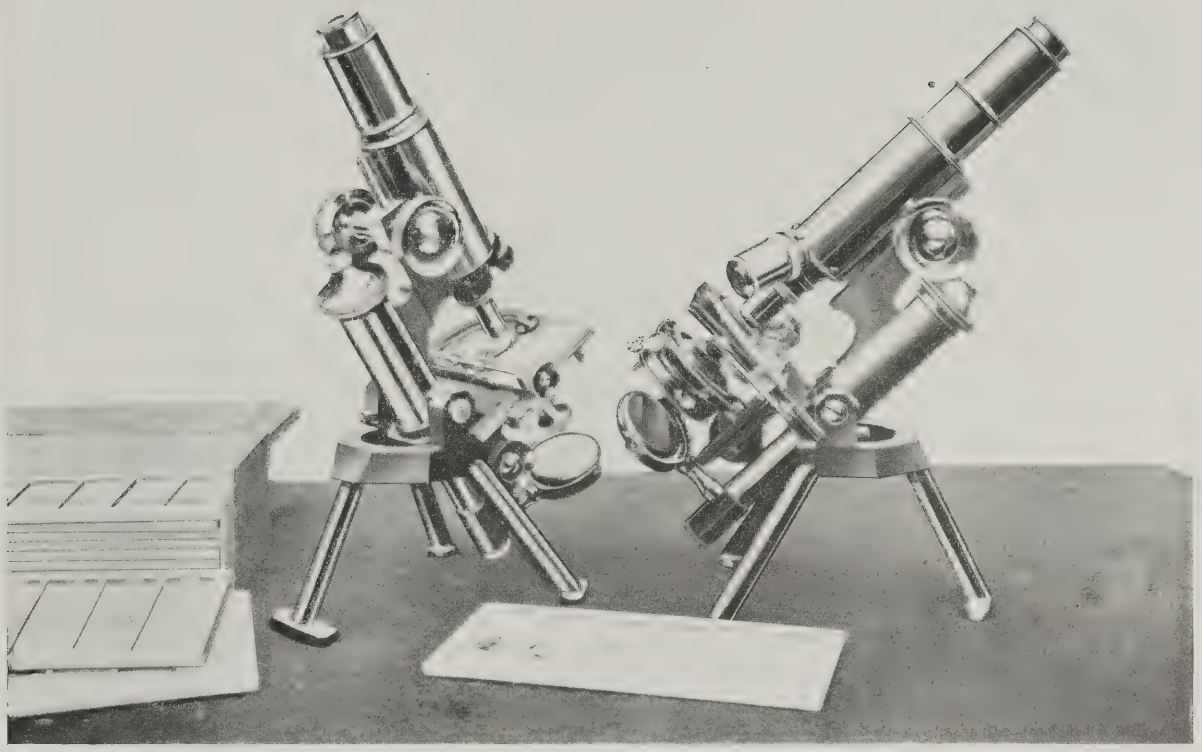


FIG. 1.

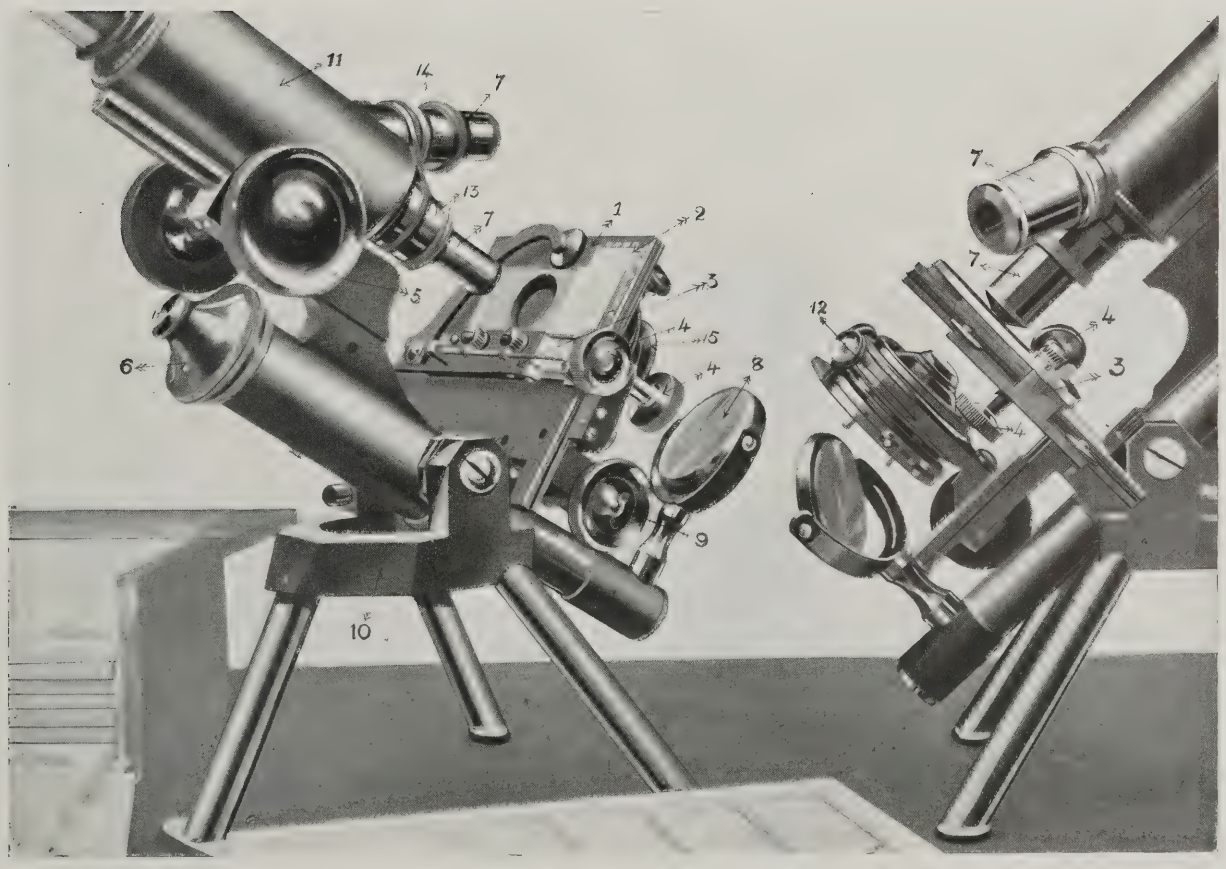



FIG. 2.

PLATE D.

Fig. 1.—PHOTO-MICROGRAPHIC APPARATUS.—1, Bellows which will give an extension of 30 inches, partly expanded; 2, Base board which carries camera and microscope, the latter rests on a portion which swings in or out; 3, Microscope fixed for photographing; 4, Metal sleeve with which a light-tight connection is made between microscope and camera; 5, A metal rod which, when turned, actuates a grooved pulley in which runs a cord to grooved milled head of fine adjustment screw; 6, Lamp; 7, Bull's-eye condenser; 8, Abbe condenser.

Fig. 2.—MICROSCOPE FIXED FOR PHOTOGRAPHING.—Below the stage is the sub-stage with Abbe condenser and iris diaphragm. Lamp in front of two cabinets. Bull's-eye condenser between lamp and microscope. The metal boxes contain objectives, two of the objectives are fixed on the double nose-piece of microscope.

## PHOTO-MICROGRAPHIC APPARATUS.

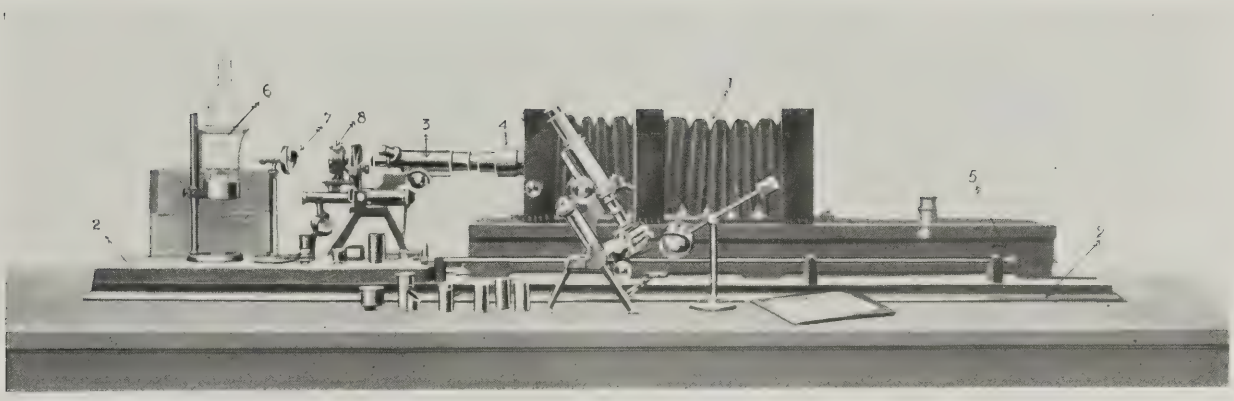



FIG. 1.

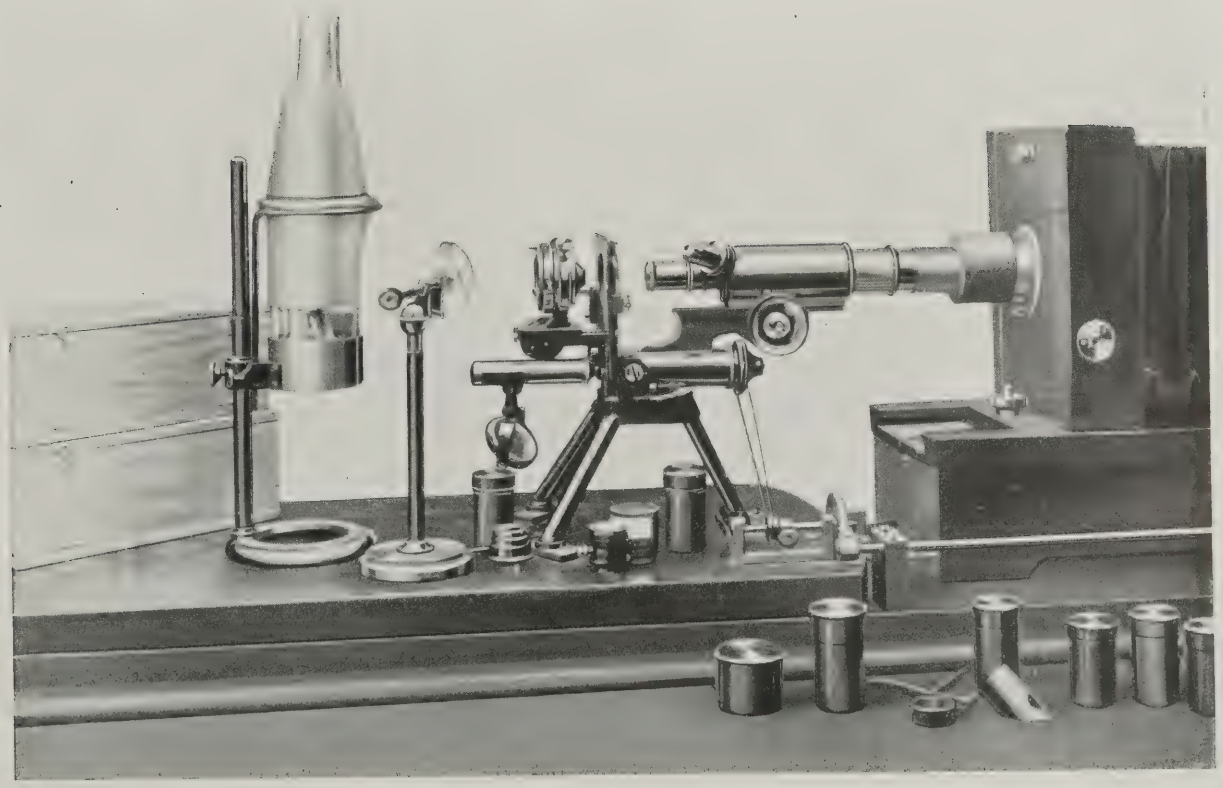


FIG. 2.

PLATE E.

Fig. 1.—Coal Dust from Screening Chamber, which has not been influenced by flame of explosion. Many of the particles are triangular in shape.

Dust collected on glass slip 60 feet beyond Downcast End of gallery, May 26th, 1908. Slide XX. $\frac{25}{15}$

Photographed by transmitted light.

Fig. 2.—Coal Dust from Pulveriser.—Particles appear rounded and have the lustre of pitch, they are generally aggregated and dusted with more minute particles of coal dust.

Photographed by reflected light, material mounted on Bristol board.

Fig. 3.—Coal Dust from Silkstone Seam which had floated in the air of the roadways and alighted as a fluff on the rim of a wheel. Particles free, not cohering, bright in appearance, and do not display the persistent pitchy lustre of pulverised coal dust, Fig. 2.

Photographed by reflected light, material mounted on Bristol board.

## Coal Dust.

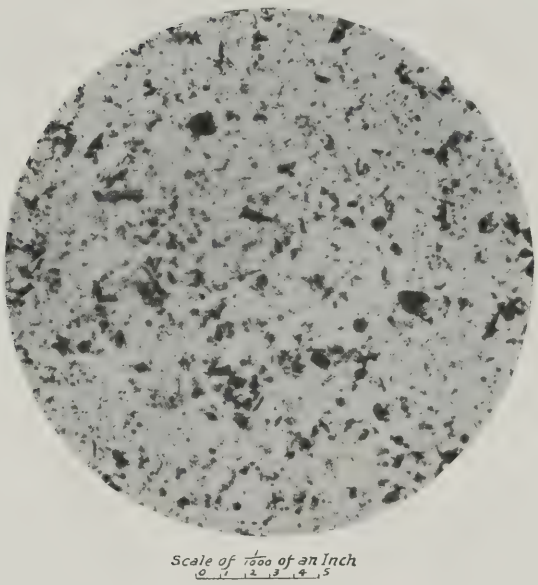



Fig. 1.

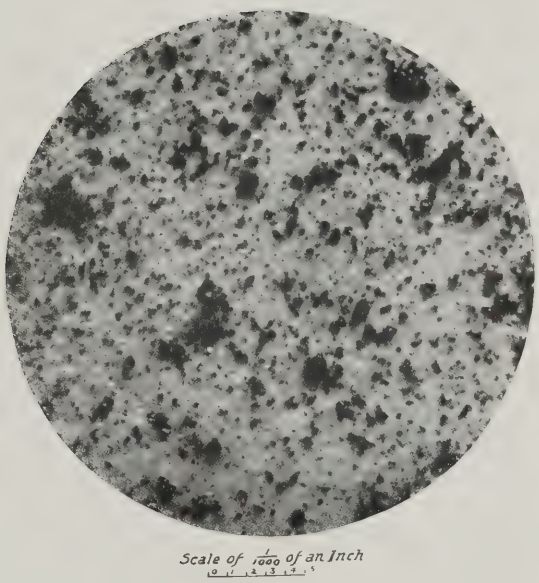



Fig. 2.

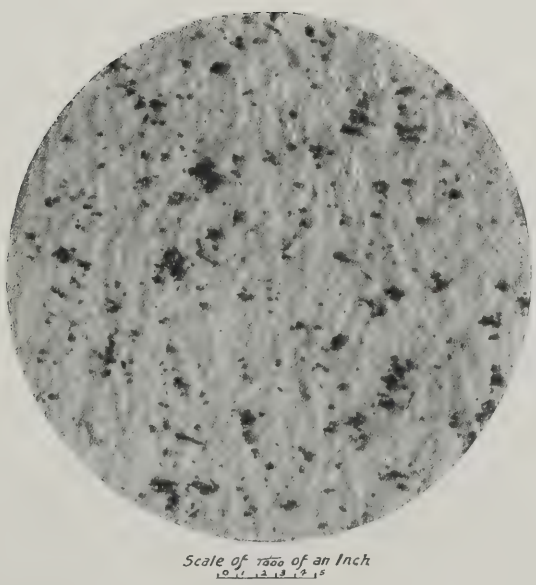



Fig. 3.

PLATE F.

Fig. 1.—Coke from Floor of Gallery, 210 feet in front of large cannon: Experiment 66. Material feebly coherent, falls into dust under the least pressure. The mass consists of films and bubbles formed when the material was in a viscous condition, and on which is a deposit of smoke.

Photographed by reflected light with ordinary camera.

Fig. 2.—Coke from Experiment 72.—Material brittle, distinctly coherent, the cement being pitch, which has overspread and interpenetrated the mass. The bubbles are highly lustrous, except where smoked. At places the film of pitch has been thrown off, and hollows are disclosed in the material which are covered with other films and bubbles of pitch. All the films are pierced with minute conical outlet holes.

Photographed by reflected light.

Fig. 3.—Edge of Fragment of Coke from Experiment 72.—Irregularly distributed hollows are seen to occupy the whole thickness of the coke, in which are also bubbles of pitch and minute outlet holes similar to those seen in the surface view, Fig. 2.

Photographed by reflected light.

## COKE.

FIG. 1.

FIG. 2.

FIG. 3.

PLATE G.

Fig. 1.—RAW TAR pressed between a cover glass and a micro-slip to illustrate the action of expressed water on a viscous body.

Slide $T_1 \frac{30}{10}$

Photographed by transmitted light.

Fig. 2.—RAW TAR. Portion of Fig. 1, enlarged.—One small islet of tar occupies the centre of the microscopic field. In the dark islets of tar may be seen outlines of bubbles of water. The grey portion is the tar water, and in it are seen minute soot particles washed out of the tar. The thread-like endings of two of the portions of tar, at the top of the slide, are of interest, as tar, when in a high state of viscosity, leaves separating threads when divided. See also "Gallery Experiment Material," Plate L, Fig. 2.

Photographed by transmitted light.

FIG. 3.—FENESTRATED PITCH.—Raw tar heated to pitch and cooled. The flow of the viscous tar and the evaporation of moisture has induced the formation of holes and their bridging with thin bands of bituminous matter. On cooling, the fenestrated pitch has cracked in zigzag directions. See also Plate I, Fig. 3.

Photographed by transmitted light

## TAR AND PITCH.

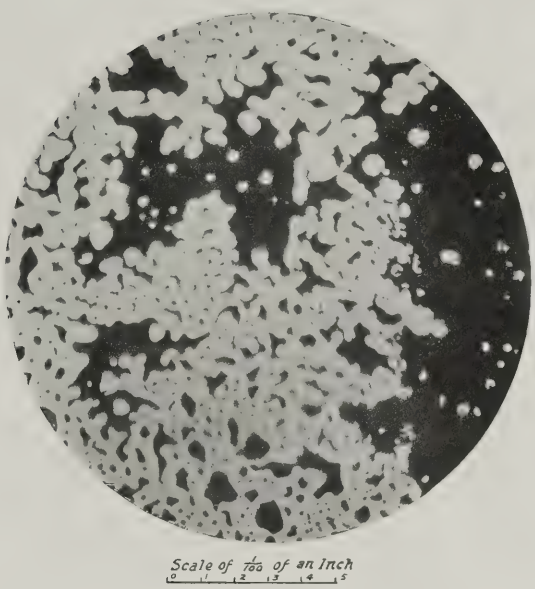



FIG. 1.

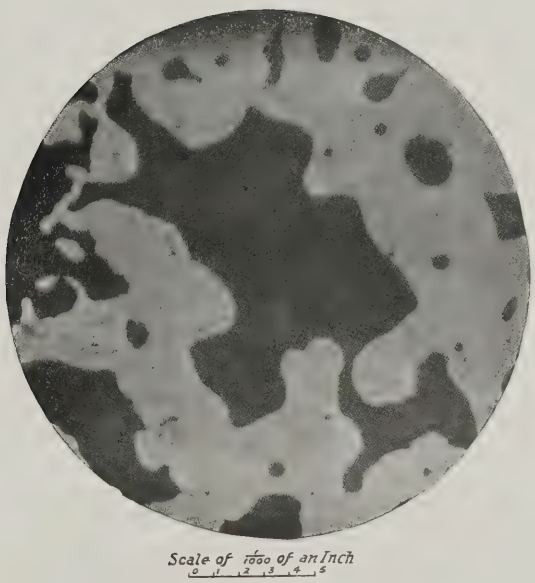



FIG. 2.

FIG. 3.

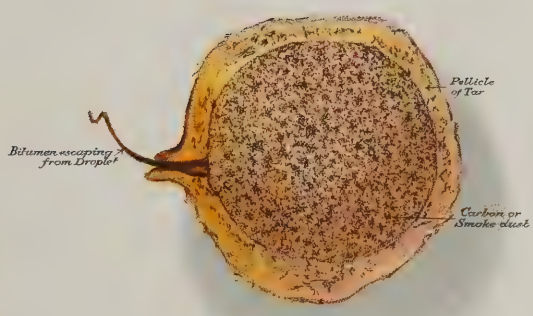
# BRITISH COAL DUST EXPERIMENTS
(1907-9).

Plate H

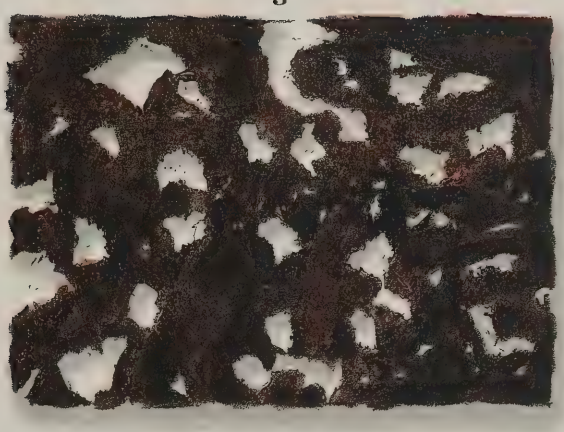
## TAR.

1

2




3



Scale.
One thousandth part of an Inch.

*1. Raw Tar with Water, Oil globules, and Smoke Dust*
*2. Droplet of Tar which has burst in falling.*
*3. Fenestrated Pitch.*

*Microscopical Section*

*Del. V.M.C.*

PLATE I.

Fig. 1.—Coal Dust Burned to a Flimsy Ash, showing that the material is covered with minute quartz particles. The camera lucida drawings, Plate J, better express the general appearance of coal dust when burned to ash. The material when thus burned does not fall, but forms bridges of silicate of iron and hollows or cavities on and in which are scattered angular quartz fragments and quartz dust.

Photographed by reflected light.

Fig. 2.—Coke on Prop fixed in Gallery.—This material is rich in carbospheres, microspheres, and fenestrated pitch This illustration should be studied in conjunction with Figs. 1, 2, 3, Plate F.

Photographed by reflected light, ordinary camera.

Fig. 3.—Tar Burned to Pitch, which on cooling has cracked. Fragments of the shapes enclosed by the cracks are common in explosion material. Sometimes portions are ejected as the material cools beneath the microscope, as on the right-hand lower corner. The round holes are such as give rise to fenestrated material, see Plate G, Fig. 3.

Photographed by transmitted light.

## Ash, Coke, and Pitch.

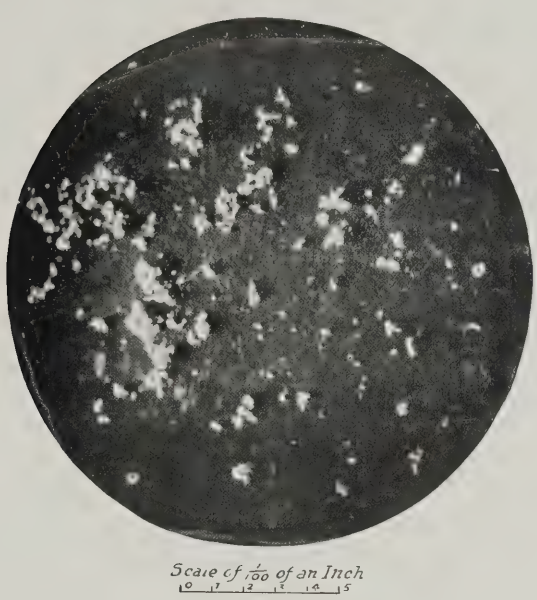



Fig. 1.

Fig. 2.

Fig. 3.

# BRITISH COAL DUST EXPERIMENTS (1907-9).

Plate J

## ASH

1

2

3

Scale.
One thousandth part of an Inch.

*Ash, left after carefully burning Coal Dust, which shews the position its constituents occupied in the Dust particles.*

*Microscopical Section*

*Del. V.M.C.*

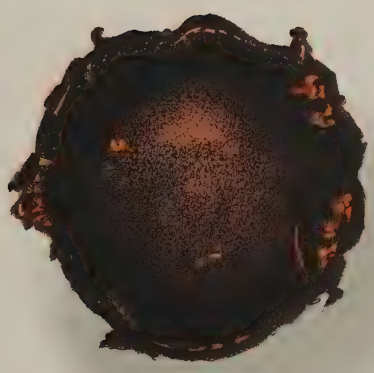
# British Coal Dust Experiments (1907-9).

Plate K

## Carbospheres.

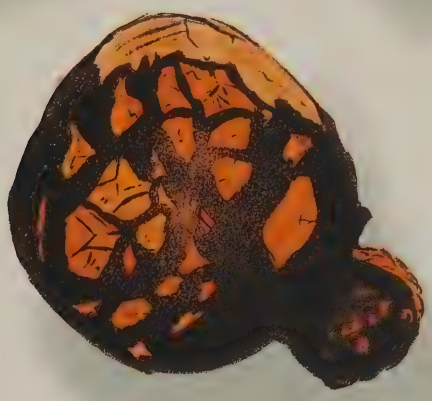
1

2

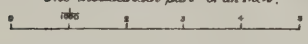


3

4



*Scale*
*One thousandth part of an Inch.*



1. *Carbosphere from Experiment N°. 58.*
2. „ „ „ „ *100, 80 feet in front of cannon.*
3. „ *made in blowpipe flame.*
4. „ „ „ „

*Microscopical Section* *Del. V.M.C.*

PLATE L.

Fig. 1.—EXPLOSION COAL DUST gathered after Altofts explosion, 1886. The large portion, upper left-hand side, is cohering coal dust, which has been heated sufficiently to cause the tar to flow and form fenestrated portions, across which are bars and films of bituminous matter, but it was not heated sufficiently to burn off all the films of tar. Some of the larger portions and the splinter-like fragments are coal. The spherical bodies are carbospheres and microspheres. The finest dust is smoke.

Slide $B_2$ $\frac{26}{14}$

Photographed by tramsmitted light.

Fig. 2.—GALLERY EXPERIMENT MATERIAL, April 24th, 1907.—General appearance of highly fenestrated pitch with many films of tar. The thread-like prolongations of many of the margins are due to the separation of the fragments when in a soft state. See Plate G, Figs. 1 and 2.

Slide $\frac{2}{07}$ $\frac{26}{10}$

Photographed by transmitted light.

Fig. 3.—GALLERY EXPERIMENT MATERIAL, May 23rd. 1908.—This dust had adhered to a glass slip fixed on end of a post 60 feet in front of Downcast End of gallery. Large microsphere, top left-hand portion of slide, a carbosphere near centre of bottom portion; both these bodies are plentiful. Fenestrated material is present in centre and right-hand side of microscopic field. Three-sided fragments of coal plentiful.

Slide $\frac{9}{08}$ $\frac{17}{23}$

Photographed by transmitted light.

## EXPLOSION MATERIAL.

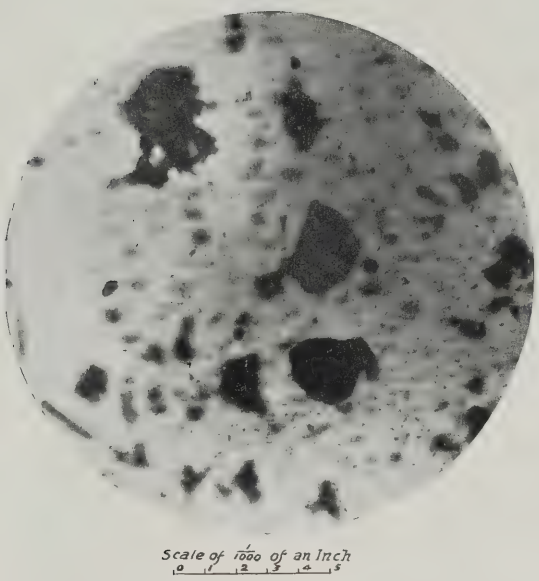



FIG. 1.

FIG. 2.

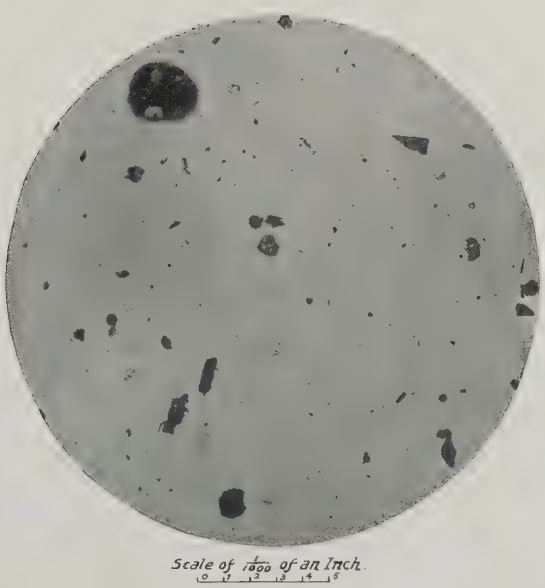



FIG. 3.

# BRITISH COAL DUST EXPERIMENTS (1907-9).

Plate M

## MICROSPHERES.

1. *Microsphere from Altofts Explosion, 1886.*

2 & 3. *Microspheres from Experiment No 9, May 23rd 1908, 60 feet in front of large cannon.*

4. *Microsphere from Experiment No 58, from a standing prop.*

5. *" " " " 62 " " prop on floor, 180 feet in front of large cannon.*

*Microscopical Section*

*Del. V.M.C.*

---

PLATE N.

Fig. 1.—FERTILE SPIKE OF SELAGINELLA, a flowerless plant from West and South Africa, and grown in British greenhouses. On the left are seen spore cases, or microsporangia, containing microspores, many of which are dehiscing in fours. Three only are seen, as one is hid by the others. See also Plate A, Fig. 3. On the right are groups of four macrospores in spore cases or macrosporangia. See Plate A, Fig. 1. Both kinds of spore cases grow in the axil of a fertile leaf or sporophyll.

Photographed by transmitted light.

Fig. 2.—OBLIQUE SECTION OF CONE OF CALAMOSTACHYS BINNEYANA, the fruit of Calamites. Section shows microspores enclosed in sporangia or spore cases. At the top of the section is seen a detached sporangium, and below are several pairs of sporangia which are pressed out of shape. Between each pair is seen the tissue of the sporangiophore or stalk, from which grew originally the sporophylls or fertile leaves and the spore cases.

The cells of the tissue of these bodies, as well as the spores, are often recognisable in coal explosion material. The calcareous coal ball of which this slide is a section is from the Coal Measures, Littleborough.

Photographed by transmitted light.

Fig. 3.—TRANSVERSE SECTION OF A CALCAREOUS COAL BALL containing the root and other tissues of Lyginodendron, among which are sporangia containing microspores. Coal Measures, Dulesgate, Todmorden.

Photographed by transmitted light.

# PLANT TISSUE.

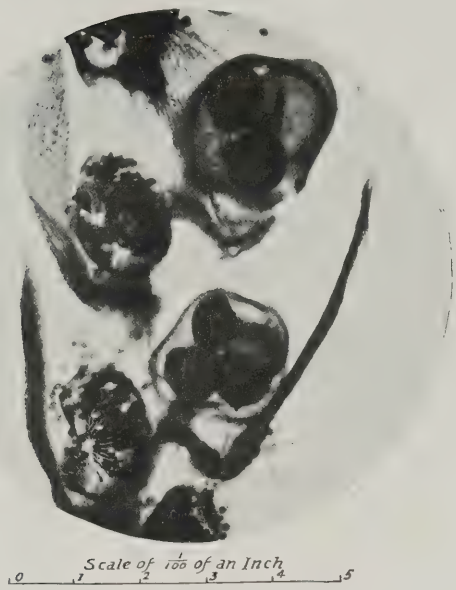



FIG. 1.

FIG. 2.

FIG. 3.

PLATE O.

Fig. 1.—FIBRES OF COTTON FIRED ON A GLASS SLIP.—Nearly all the fibres were browned, but some were blackened and the ends thickened, and formed balls which, on the merest touch, were detached. Fenestrated particles are seen on the microscopic field.

Photographed by transmitted light.

Fig. 2.—GUN-COTTON TUFT GATHERED IN COAL DUST ZONE of gallery after Experiment No. 57.—The fibres have swollen and cohered; some are blistered. Dust from the explosion has adhered and in some cases penetrated the fibre when it was soft. See also Plate P, Fig. 1.

Photographed by transmitted light.

Fig. 3.—FIBRES FROM A GUN-COTTON TUFT suspended 22 feet in stone dust zone in gallery, during Experiment No. 109. The fibres have neither swollen nor cohered, probably owing to absence of moisture.

Photographed by transmitted light.

## COTTON FIBRES.

FIG. 1.

FIG. 2.

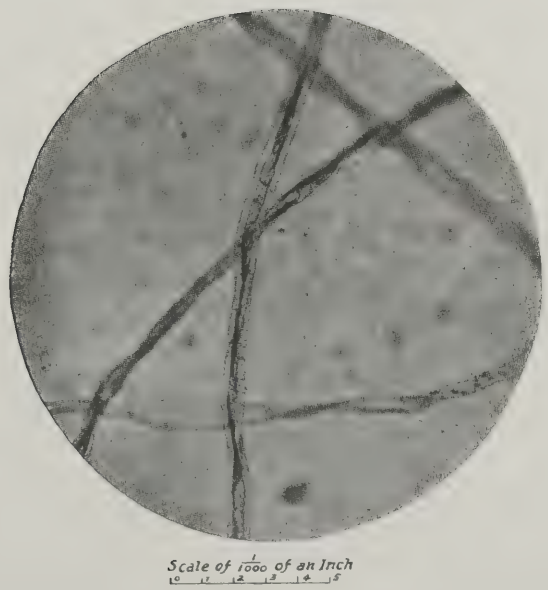


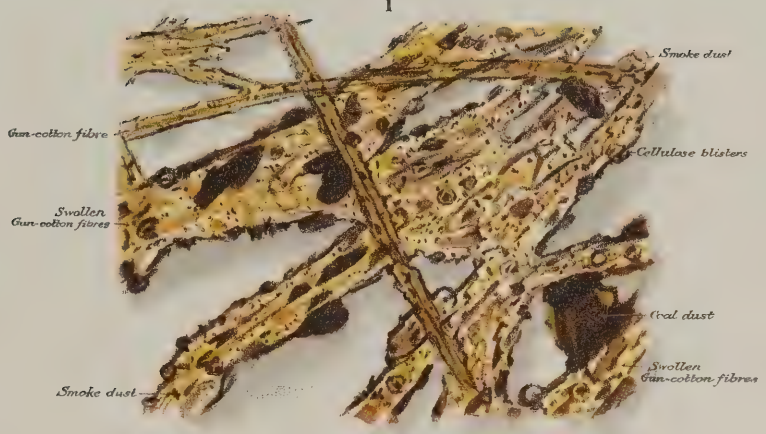

FIG. 3.

# BRITISH COAL DUST EXPERIMENTS
(1907-9).

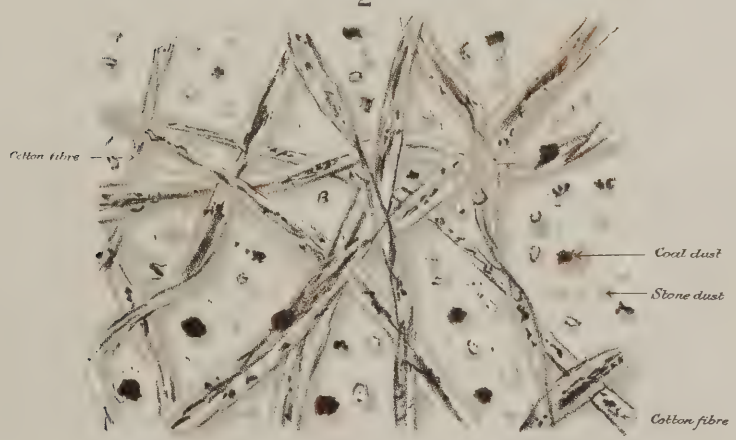
Plate P

## COTTON STRANDS.

1




2




3

*Scale.*
*One thousandth part of an inch.*

*1. Experiment N° 57. Gun-cotton fibres gathered* INSIDE GALLERY *from Coal Dust Zone.*

*2. Experiment N° 109. Cotton fibres gathered* INSIDE GALLERY, *22 feet in Stone Dust Zone.*

*3. Swollen and cohering Gun-cotton fibres; material was heated over water and exploded at 166° C.*

*Microscopical Section*

*Del. V.M.C.*

PLATE R.

Fig. 1.—STONE DUST FROM PULVERISER as used for experiments in stone dust zone. The material has a tendency to aggregate in small masses.

Photographed by reflected light.

Fig. 2.—STONE DUST.—The larger portions are aggregated particles of shale through which light penetrates in places. Its granular material is transparent, so that the minute, dull, black, carbonaceous particles, which give colour to the shale, can be traced within and on particles. This material is from Experiment No. 63, and shows that many of the coal dust particles, when sufficiently heated to distil their tar products became tacky and adhered with their tarry surfaces to the stone dust.

Photographed by transmitted light.

Fig. 3.—STONE DUST similar to Fig. 2, but also showing silica flour and fragments of coal. See also Plate S, Figs. 1-4.

Photographed by transmitted light

## Stone Dust.

Fig. 1.

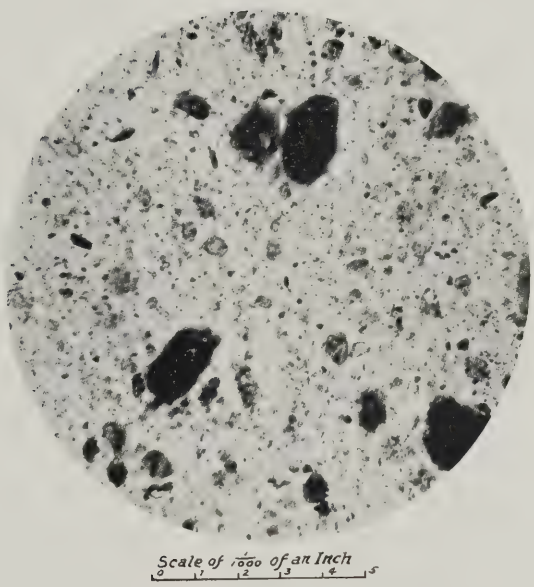



Fig. 2.

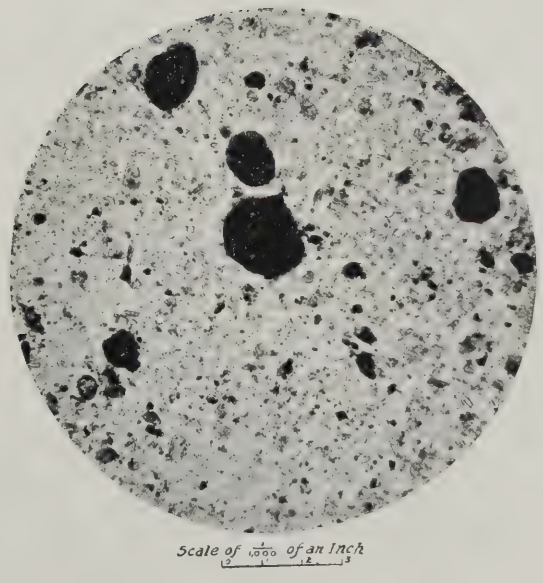



Fig. 3.

# BRITISH COAL DUST EXPERIMENTS (1907-9).

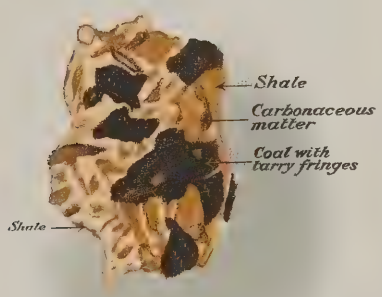
Plate S

## STONE DUST WITH ADHERING COAL DUST.

1

2

3




4

Scale.
One thousandth part of an Inch.

*1. Experiment No 63. From floor 65 feet in front of large cannon.*

*2,3,&4. " " " " 126 " " " " "*

*Microscopical Section.*

*Del. V.M.C.*

# BRITISH COAL DUST EXPERIMENTS
(1907-9).

Plate T

## ACTION OF HEAT ON SHALE.

1

2

3

4

Scale.
One thousandth part of an Inch.

1. *Fragment of Blue Bind or Shale in natural state, unburned.*
2. *" " " " " heated to redness and washed.*
3. *" " " " " heated to redness.*
4. *Pulverised Shale or Stone-dust from floor of gallery 65 feet in front of large cannon. Experiment Nº 63.*

*Microscopical Section*

*Del. V.M.C.*

After Experiment No. 12* five samples were obtained. Two, taken from posts fixed 30 ft. in front of the downcast end, contained thin particles of coal, shreds of tar, carbospheres, micro-dust, and microspheres of from $\frac{1}{300}$ to $\frac{1}{400}$ in. diameter. When the dust was polarised particles of quartz and vegetable fibre were recognised.

Two other samples, from posts 60 ft. in front of the downcast end, contained fragments of coal with lenticular patches similar to sections of macrospores, and other fragments showing fossil pitted wood tissue. There were also fossil plant spores and a few microspheres.

The fifth sample, from a post 90 ft. in front of the downcast end, contained no microspheres, but showed a large quantity of particles of quartz.

A sample taken from a prop inside the gallery after Experiment No. 58 contained portions of fenestrated bituminous matter, coke, carbospheres, and a large number of microspheres. The number of microspheres present was about 100 to the square inch.

In addition to the larger bodies recognisable among the dust collected after an explosion, there is always present a large quantity of very fine dust or smoke. (Plate L, fig. 1).

The smoke from burning coal dust was collected and examined. Under a high magnification the particles so diffracted the light that it was difficult to determine definitely their shape and size. By using different methods of illumination, however, it was possible to detect angularities and differences in size. With careful manipulation of a vertical illuminator many of the particles appeared to be of a brownish-black colour, and when measured had an average diameter of from $\frac{1}{30,000}$ to $\frac{1}{40,000}$ inch.

These smoke particles were the smallest objects that could be detected among the material after an explosion.

*The Examination of Cotton Tufts used to Indicate Flame.*—With a view to procuring evidence of the presence of flame in the gallery during an explosion, paired tufts of cotton wool and guncotton yarn are fixed before an experiment about a yard apart along the gallery.

The examination of a few of the fibres from a tuft of guncotton exposed during Experiment No. 57 showed that while some of the fibres were not altered, others showed signs of flame. Some fibres were slightly browned or blackened and had become brittle, others had blistered or had swollen and attached themselves to other fibres. (Plate O, fig. 2 and Plate P, fig. 1.) If by any movement the attached fibres had separated for a short distance, a gelatinous film connected them (*ibid.*) ; if movement had continued further the film was ruptured into a series of threads which had hardened (*ibid.*).

Experiments were made for the examination of the appearance of cotton wool and guncotton yarn after being heated.

Cotton wool when heated on a glass slip browned and burned, the burnt ends becoming globular and often breaking off. (Plate O, fig. 1.)

On heating the cotton wool in a glass flask over a spirit lamp it burned at 200 degs. Cent. (392 degs. Fahr.). On examination many of the fibres were seen to have swollen, and some of their ends showed thickenings, but none had cohered.

* The flame of the explosions in Experiments Nos. 9, 10 and 12 shot out beyond the downcast end 90, 180 and 150 feet respectively.

Guncotton yarn, when heated in a flask containing a little water, exploded at 166 degs. Cent. (330 degs. Fahr.). Under the microscope many of the fibres remaining were seen to be blackened and to have rounded ends. Other fibres were swollen and had cohered and presented features similar to those of samples taken from the gallery after an explosion. (Plate P, fig. 3.) The more highly steam saturated strands had not exploded.

On repeating the experiment, the guncotton exploded at 175 degs. Cent. (347 degs. Fahr.). The appearance of the residue was similar to that from the last experiment ; many of the fibres had blackened and portions with swollen ends had become detached, whilst some had swollen and cohered.

When guncotton yarn was heated in a glass flask containing a little coal dust, distillation products condensed on the suspended fibres, but no explosion took place even when the thermometer fixed near the guncotton indicated a temperature of 200 degs. Cent. (392 degs. Fahr.). Beneath the microscope the fibres were seen to be covered with tar which had formed small drops where the fibres crossed.

After washing the fibres with benzene, some portions were seen to have been charred, whilst other portions had swollen slightly or cohered and bubbles had formed in the fibres.

In addition to registering the passage of flame, the cotton wool and guncotton tufts taken from the gallery after an explosion always retained minute particles of coal dust and of the products of the action of heat on coal dust. (Plate O, fig. 2, and Plate P, fig. 1.)

Thus, a sample of guncotton yarn taken from the gallery after Experiment No. 57 had adhering to it particles of coal dust, fenestrated tar, microspheres and smoke. The fibres contained bubbles.

A sample of cotton wool gathered from Valve No. 3 after Experiment No. 62 was found to be burned by the flame. The strands had not swollen. They retained particles of unburned coal dust, dust with fringes of tar, microspheres and smoke.

A tuft of cotton wool taken from a position 22 ft. from the beginning of a stone dust zone in Experiment No. 109 had about nine-tenths of its fibres untouched by flame. (Plate O, fig. 3, and Plate P, fig. 2). A few strands had become singed but none had cohered.

*The Examination of Stone Dust.*—The stonedust used in the experiments is obtained by pulverising the grey bind which lies 3 ft. above the Diamond seam. It consists mainly of aluminium silicate and contains oxides of iron and carbonaceous matter which give to it its colour. (Plate T, fig. 1.)

A series of examinations of samples of the dust collected after experiments in which a stone dust zone had been employed showed :—

That portions of the coal dust intermixed with the stone dust had not been acted upon by heat. (Plate R, figs. 2 and 3.)

That other portions had been slightly heated but not sufficiently to enable them to cohere.

That some particles had been sufficiently heated to cause them to adhere to fragments of stone dust by means of tacky fringes similar to those seen in heated tar. (Plate R, figs. 2 and 3 ; Plate S, figs. 1-4.)

That many of the stone dust particles had been heated during the explosion. (Plate T, fig. 4).

In addition to the foregoing these microscopical investigations show :—

That there is present among mine dust a large quantity of particles so minute as to be invisible to the naked eye. That coal dust in an explosion may be either partly burned or may be burned to coke or may escape the flame. That many of the particles of coal dust remaining after an explosion have cohered. That there is evidence of the action of steam.

The conclusions to be drawn from any microscopical investigation must rest, of necessity, upon cumulative evidence. The tabulation of all the evidence obtained in this investigation from the examination of the 300 or more slides would form a treatise in itself, and it would be obviously misleading to state conclusions without producing all the evidence from which those conclusions are drawn. The scope of the present Report does not admit of more than the outlining of the scheme of the work, and the placing on record, without much comment, of a few of the facts observed.

# PART II.

The first part of this Report treats of the practical demonstration of the explosive properties of coal dust, and of the endeavours that have been made to obtain a reliable remedy.

The Committee believe that it will be of interest to many to place also on record the main facts that have been established regarding the mode of propagation of coal dust explosions, in order that it may be seen to what extent the conclusions derived from the practical tests are supported by scientific investigation.

They have, therefore, asked Dr. Wheeler to prepare a statement regarding the lines upon which the work is progressing, and to give an explanation of such points as have arisen in the course of the enquiry upon which information has been obtained.

Since, however, the investigation is still in progress, they think it preferable to reserve for a future Report the account of the major portion of the work which has been done.

CHAPTER I.

# THE MODE OF PROPAGATION OF COAL DUST EXPLOSIONS: Introduction.

So far as it has been possible to judge from a study of the physical and chemical phenomena accompanying the development of an explosion in mixtures of air with a finely divided inflammable solid such as coal dust, such mixtures behave in a somewhat similar manner to mixtures of air with an inflammable gas; that is to say, for example, the pressure attained and the velocity with which that pressure is propagated are of the same order of magnitude.

Since, therefore, a considerable amount of experimental work has been done with gaseous mixtures, and the laws which govern the propagation of explosion in them determined with more or less exactness, it is profitable to refer to the main outlines of such work in order that it may be seen to what extent it is possible to determine on similar lines the laws governing the combustion of mixtures of dust and air.

## THE COMBUSTION OF GASEOUS MIXTURES.

Combustion of a gas—that is to say, its chemical combination with oxygen—can take place in two ways which differ only in degree: in the one case the combination can take place slowly without any apparent physical phenomena such as light and heat; in the second case the combination can be rapid, when both light and heat and, in consequence, pressure or expansion are produced.

The discovery of the former mode of combination is due to Sir Humphry Davy, who studied the phenomena in 1815 in connection with his investigation into the cause of accidents arising from the explosion of firedamp in coal mines. Having demonstrated that there was no appearance of flame during the combustion, at a comparatively low temperature, of a mixture of combustible gas and air in sealed tubes, Davy proceeded to show that for flame to be propagated through a combustible mixture it was necessary that each successive layer of gas should be raised to a certain definite temperature.

This temperature has been designated the "ignition temperature." It is the lowest temperature at which rapid inflammation of the gas can take place.

Davy* was also the first to make any measurement of the speed at which inflammation was propagated through a gaseous mixture. When gas from the distillation of coal (which he found to be more inflammable than firedamp) was mixed with eight times its volume of air, and was fired in a tube 1 ft. long and $\frac{1}{4}$ in. in diameter, the flame took more than a second to traverse the tube.

In addition to determining the speed at which inflammation spreads through the

* *Phil. Trans.*, 1816. Collected Works. Vol. 6, p. 26.

gaseous mixture, it is important also to know the manner of its spreading. The classical investigations of H. B. Dixon* have gone far towards giving complete information on both these questions.

In order to determine the facts experimentally, it has been necessary to employ tubes of comparatively small diameter, and it may be objected that the smallness of the tubes renders the results of merely academic interest. Such, however, is not the case, for all the workers in this field have found that above a certain small limit the diameter of the tubes has no effect on the results obtained : or, in other words, that cooling by the walls of the tube does not exercise a preponderating influence except when the tube is very small.

The general conclusions to be drawn from the work that has been done in this manner are as follows :—†

When ignition of a mixture of combustible gas and air has been effected at the *open end* of a long tube closed at the other end, the flame can be propagated in two principal ways :—

1. By Simple Transmission (by Radiation and Conduction) of the Heat Developed by the Burning of one Layer of Gas to the Layer Adjacent to it.

It is evidently essential that, for the inflammation to be propagated at all in this manner, the heat developed by the combustion of the gas must be capable of imparting to the uninflamed gas in front of it a temperature greater than the ignition temperature of that gas. This condition will not be fulfilled if the proportion of combustible gas or of oxygen in the mixture is too small, so that gaseous mixtures are only inflammable between two limits—the "lower limit" corresponding with the minimum amount of combustible gas, and the "higher limit" corresponding with the minimum amount of oxygen.

The flame travels along the tube at a uniform speed for a short distance and then develops vibrations, swinging backward and forward with oscillations of increasing amplitude which sometimes attain extraordinary violence ; finally, in certain cases, the propagation of inflammation may become practically instantaneous, or at least so rapid that it is very difficult to determine any definite velocity.

This last stage constitutes the second way in which inflammation may be propagated, namely,

2. By the Transmission of a Sufficiently High Pressure.

A high pressure suddenly applied develops a sufficiently high temperature in the gas to raise it above its ignition temperature ;‡ the combustion of the gas then causes a further rise in temperature, and consequently a further increase in pressure. In this manner the inflammation is propagated almost instantaneously. This phenomenon, discovered by Berthelot in 1881 and named by him "*l'onde explosive*"

* "The Rate of Explosion in Gases," Bakerian Lecture, *Phil. Trans.*, 1893. "The Movements of the Flame in the Explosion of Gases," *Phil. Trans.*, vol. 200A, 1903.

† *See* also Bunsen, *Ann. Chem. Phys.*, vol. 131 ; Bunsen, *Phil. Mag.*, vol. 34, 1867 ; Berthelot, *Ann. Chem. Phys.* (5), 28, 1883 ; Berthelot, "Sur la force des Matières Explosives," vol. 1, chap. 7 ; Mallard and Le Chatelier, *Compt. Rend.*, 1881, 145 ; Mallard and Le Chatelier, *Ann. des Mines* (8), 4, 1883.

‡ According to the law of adiabatic compression of gases, a gaseous layer suddenly compressed to 50 atmospheres would be raised to about 1,000 degs. Cent. (1,832 degs. Fahr.), *i.e.*, much higher than the ignition point of most combustible gases.

To face page 146

# PLATE XIV.

FIG. 1.

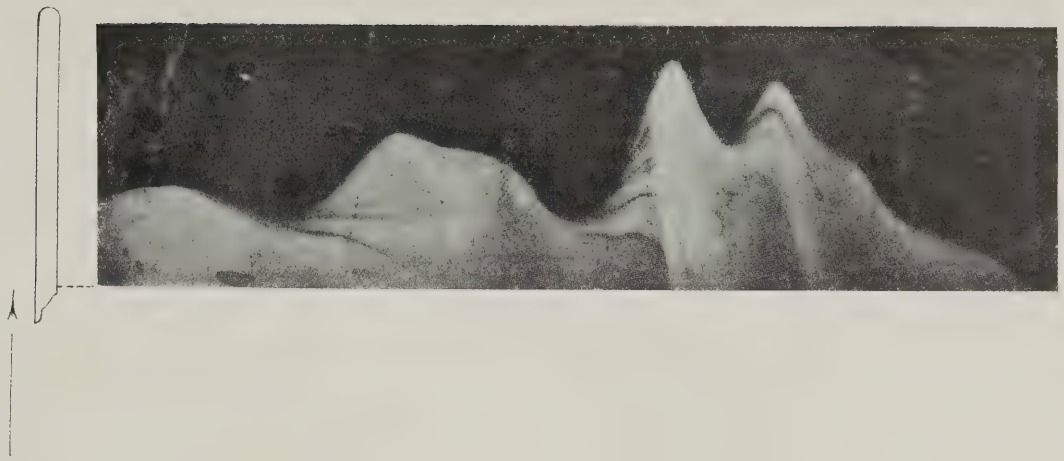


FIG. 2.

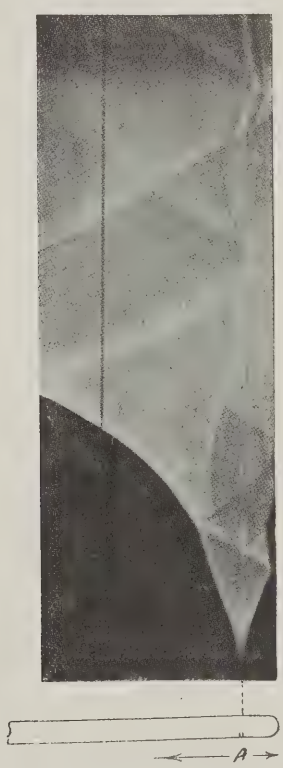



FIG. 3.

**The Flame in the Explosion of Gases photographed upon a rapidly moving film.**

The tube in which the explosion was taking place is shown diagrammatically with each photograph; it is the image of this tube, (rendered luminous by the explosion), which is photographed, the image being drawn out owing to the rapid movement of the film, and thus enabling the movements of the flame to be recorded.

The direction in which the explosion is travelling is indicated by the arrows; thus, in fig. 1, the flame has been photographed just as it entered the last foot of a tube 5 ft. long; in fig. 2, ignition was effected right at the end of the tube (at A), and the photograph shows the flame of the explosion from its beginning; in fig. 3, ignition took place at A, and the flame is shown travelling in both directions.

is now called the "detonation-wave";* it is characterised not only by its great velocity of movement but by its intense luminosity and the high pressures instantaneously set up in it.

The high pressure necessary to transform the ordinary propagation of combustion into the detonation-wave may arise from a variety of causes:—

(*a*). The oscillations during the vibratory movements, which are merely a succession of compression and rarefaction waves, may become of very large amplitude and thereby cause sufficient compression.

(*b*). At the moment of inflammation near the *closed end* of a tube a compression wave is formed; this wave may be reflected back from the end of the tube and overtake the flame.

(*c*). An obstruction or constriction in the tube may cause a compression wave.

When ignition takes place at the *closed end* of the tube instead of at an open end, the flame travels at a rapidly accelerating speed and no vibratory movement takes place except in very narrow tubes.

What has been stated in this short summary refers only to mixtures of a combustible gas with *air*: mixtures with *pure oxygen* behave somewhat differently, the preliminary period of uniform movement is shorter, a rapid acceleration follows, and this is immediately succeeded by the detonation-wave, without any vibratory movement taking place.

Dixon has studied the movement of the flame during explosion by photographing it upon a film revolving at a speed of about 50 m. per second, and in this way has been able to explain a large number of facts. The photographs in Plate XIV. have been reproduced from his paper in the Royal Society *Transactions*† in order to illustrate some of the points that are dealt with in this Introduction.

Fig. 1 shows the oscillations of the flame during the vibratory propagation of explosion in a mixture of carbon disulphide and nitric oxide ($CS_2 + 8NO$). The mixture was fired at the open end of a tube 5 ft. long and of 1 in. bore. Only the last foot of the tube is shown in the photograph.

In fig. 2 the transition to the detonation wave of an explosion of slow propagation is illustrated. A mixture of cyanogen and *oxygen* ($C_2N_2 + 2O_2$) was employed, and the explosion was started at the closed end of the tube. The first part of the curve shows the practically uniform movement of the flame at a comparatively slow rate of propagation; the last part shows the sudden development of the more luminous and more rapid detonation wave.

A photograph of particular interest is reproduced in fig. 3. A mixture of carbon disulphide and oxygen ($CS_2 + 5O_2$) was used, and firing was effected 4 in. from a closed end. The flame begins to travel right and left from the point of ignition with equal velocity in both directions. It will be seen, however, that the flame does not travel direct to the near end of the tube (right hand), but, while still a short distance from it, recedes and again approaches with an oscillatory movement, which is repeated before the flame finally reaches the end of the tube. From the

* *See* Note at end of chapter.

† *Loc. cit.*

point where the flame is first checked, a luminous wave is seen running back and overtaking the main flame, *which at this point acquires greater brightness and velocity.*

Taking now as a concrete example an explosive mixture of firedamp and air, the following facts are known. The ignition temperature is about 600 degs. Cent. (1,112 degs. Fahr.), so that the initial source of heat necessary to cause inflammation of an explosive mixture of firedamp and air must have a temperature higher than this. In order that the inflammation may be *propagated* throughout the mixture, it is further necessary that the heat developed by the combustion of any one portion of the mixture must be sufficient to raise the contiguous layer to the ignition temperature; the higher limit for firedamp that will admit of this taking place is generally stated to be 16 per cent., and the lower limit 6 per cent., under ordinary conditions.*

If ignition takes place at the *open* end of a long tube the flame travels for a short distance at a uniform speed, which varies with the proportion of firedamp present, and is about 0·6 m. (23·4 in.) per second for the mixture of maximum speed. This speed is that of the inflammation when propagated simply by conduction of heat from one layer of gas to another, and the distance travelled by the flame at this uniform speed is not very great, since it soon begins to vibrate. It is difficult to give any exact figure for the speed of the flame during the vibratory period which follows, since it fluctuates so much; the mean forward velocity is, however, always greater than the speed of the uniform movement, and may exceed 20 m. (65 ft.) per second, while for short distances it may be much greater.

These vibrations then continue with varying speeds for the whole length traversed, for, according to Berthelot and Dixon, the detonation wave with its accompanying high velocity and great pressure, is not set up in mixtures of firedamp and air.†

If ignition takes place at the *closed* end of a tube, and the explosion can travel towards an open end, the speed at which the flame travels increases rapidly to over 1,000 m. (3,250 ft.) per second without any great fluctuations, but does not appear to approach the extremely rapid movement of the detonation wave.

The different phenomena that accompany an explosion of firedamp and air depending on whether ignition is effected at the open or at the closed end of a tube are well illustrated by what occurs in a mine when a naked light is introduced at the open or at the closed end of a *cul-de-sac* filled with an explosive mixture. In the first case, the combustion takes place quietly and very little damage is done; in the second case, a violent explosion occurs, attended by great mechanical effects.

## COAL DUST EXPLOSIONS.

Turning to the problem of explosion in a mixture of a finely divided combustible solid and air, it will be seen that there is no reason why broadly similar laws should not hold good such as have been established for gaseous mixtures. The more

* *See* page 146.

† It is possible that in the roadway of a mine, where the cooling effect of the walls is entirely elimininated so far as the main bulk of the gaseous mixture is concerned, and obstructions such as props and timber may cause numerous compression waves, the temperature of the mixture may become so great that the speed of propagation of the flame and the pressure set up may approach very nearly to that existing in the detonation wave. This point is being investigated experimentally, for, as is shown later, similar effects are produced in explosions of coal dust and air.

finely divided the solid, the more nearly does it approach to the condition of a gas or vapour; and, if of sufficient lightness to remain in suspension in the air for some time and thus form an intimate mixture with the air, there is no reason why a flame once started should not be propagated throughout any length.

Just as in gaseous mixtures there will be a definite ignition temperature for each kind of dust, and inflammation will not be propagated until each successive layer has been raised to that ignition temperature. It cannot be expected, however, that the speed at which the flame will travel can ever be as great as in the more rapid of the gaseous explosions; for the heat of combustion of the fine dust first enflamed has to be transmitted from one dust particle to another, instead of from one gas molecule to another; and however dense the cloud of dust may be, the particles can never be so close together as are the molecules of a gas. The rate at which inflammation travels would, therefore, appear to depend on at least three factors — the inflammability of the dust, the fineness of the dust and the amount of dust in suspension. In dealing with dust from coal, however, a complication arises from the fact that a mixture of inflammable gases can be evolved from it at a comparatively low temperature—lower than its ignition temperature—so that, in this case, each dust particle may be partially converted into gas before actual ignition; and if the particles are close enough together, and the gas is evolved sufficiently rapidly, the subsequent combustion may give rise to phenomena more nearly comparable, both in nature and degree, with those of a gaseous explosion.

That it is not essential, however, for a dust to be capable of yielding an inflammable gas by distillation in order to form an explosive mixture with air, is shown by the many instances on record of explosions occurring on the accidental ignition of dust clouds composed of such substances as sulphur, cotton, cork, soap, flour and rice, some of which yield no inflammable gas on distillation; while an explosion with finely powdered wood charcoal has been obtained in the Experimental Gallery.

Considerations of this nature have made it seem desirable to attack the problem in the first instance along the same lines which have been so successfully followed in dealing with gaseous explosions in the hope of being able to discover the laws that govern their propagation, and, in consequence, the laws also which govern their extinction.

# NOTE III.

## THE DETONATION WAVE.

The indiscriminate use of the word "detonation" as applied to explosion having resulted in some confusion, Professor H. B. Dixon has kindly contributed the following note, in which, as the originator of the term "detonation-wave," he explains its significance. It is, of course, quite permissible to speak of an explosion as being accompanied by a loud detonation—signifying a loud noise; but it is probable that by use in this way the wrong application has arisen. The important question to decide is whether the "detonation-*wave*" (explosion-*wave*) can be developed by the explosive combustion of a gas or of coal dust.

Note by Professor Harold B. Dixon, F.R.S.

"The expression *L'onde Explosive*, coined by Berthelot, and its English equivalent 'The Explosion "Wave,' signify that flame which passes through a uniform gaseous mixture with a permanent maximum "velocity. The rate of the 'explosion-wave' is a definite physical constant for each mixture; the "explosion-wave travels with the velocity of sound in the burning gas which itself is moving rapidly "forward *en masse* in the same direction, so that the explosion-wave is propagated far more quickly than "sound travels in the unburnt gas.

"When an explosive mixture is fired by a spark or flame in a long tube, the flame is usually "propagated along the tube with an increasing velocity until, at a certain distance from the ignition point "(according to the nature of the gases), the explosion-wave is set up—if this can be propagated through "the mixture.

"The firing of a fulminate in such a mixture sets up the explosion-wave *at once*.

"In other mixtures the explosion-wave cannot be set up under ordinary conditions, *e.g.*, in mixtures "of firedamp or of coal gas and air. In these cases the flame is propagated irregularly or with vibratory "oscillations, and the flame is sometimes spontaneously extinguished. Whereas the pressure in the "explosion-wave is constant, it is quite irregular in 'vibratory' explosions.

"In the explosion-wave each layer of gas is compressed so suddenly that it is raised beyond its "ignition point by the heat of compression, and in burning it compresses in turn the unburnt layer in "front of it. The chemical combustion is much more intense and rapid than in the ordinary flame of "explosion, and as a result the gases cool much more quickly *behind* the explosion-wave.

"I use the word 'detonation' to express the burning taking place in the explosion-wave, since a "'detonator' when struck burns in this way itself and sets up an explosion-wave in explosive gases "round it. (Signed) "Harold B. Dixon."

## CHAPTER II.

# THE MODE OF PROPAGATION OF COAL DUST EXPLOSIONS—continued.

CHAPTER II.

## THE MODE OF PROPAGATION OF COAL DUST EXPLOSIONS—*continued.*

### EXPERIMENTS IN THE GALLERY.

This Report must consist, as far as this part of the enquiry is concerned, largely of an outline of preparations that have been made for studying the problem systematically, such preparations having necessarily occupied the major portion of the time that has elapsed since the work was decided upon.

It is possible, however, to place on record several important facts that have been established during the course of preliminary trials made while the experimental method was still incomplete.

It will readily be understood that every endeavour has been made to obtain such conditions as will render one experiment strictly comparable with another. In the experiments here recorded two factors—the means of ignition and the manner of distribution of the dust—have been liable to divergence from the standard aimed at, and have thus been capable of influencing to a certain extent the results obtained. Great caution has therefore been exercised in drawing conclusions from the facts recorded where comparison has been made between one experiment and another: specific phenomena, on the other hand, can be more definitely established, and it is such that are chiefly dealt with here.

Of the facts that have been observed, the most important, having regard to their bearing upon the manner in which coal dust explosions are propagated, are :—

(1.) The absence of any permanent type of "wave" of pressure, at any rate for such lengths of dust and air mixture as have been experimented with.

(2.) The marked influence of the presence of obstructions in the path of the explosion.

(3.) The possibility of propagating an explosion through a cloud of wood-charcoal dust and air.

The necessity for being able to experiment with lengths of coal dust "zone" of 1,500 ft. and upwards becomes increasingly apparent as the work proceeds ; for, as far as can be judged at present, the velocity of the explosion and the pressure developed become greater the further the explosion can travel in a dust-laden atmosphere, and it is of the utmost importance, from the point of view of establishing any remedy, to know whether a maximum pressure and velocity are reached and *maintained*,* or whether they continue to fluctuate in the same manner as is apparent during the first 300 or 400 feet of travel.

* The possibility exists of the *detonation wave* being developed after the explosion has proceeded a certain distance. A remedy which might suffice to check the explosion during its initial stage would not be proportionately effective in dealing with the detonation wave, since the pressure accompanying the wave is greatly superior. The experiments recorded in this Report must, according to our present knowledge, be regarded as treating of the *initial* stage of the explosion only.

### 1. Increase in Pressure with Increased Distance of Travel.

The increase in the pressure with the distance that the explosion travels is well illustrated by the three experiments, Nos. 54, 53 and 62, of which details are given in Table IV.

The recording manometers (A and B) were fixed on the gallery at distances 50 and 150 feet from the downcast respectively, the position of the point of ignition being as follows :—

| Experiment No. | Position of point of ignition. |
|---|---|
| 54 | 275 ft. from downcast |
| 53 | 300 „ „ „ |
| 62 | 425 „ „ „ |

so that the two manometers recorded the development of the explosion over distances of 125, 150, 225, 250, 275 and 375 feet.

In the case of Experiment No. 62, a "dustless zone" of 100 ft. was placed 50 ft. from the downcast, the remainder of the length of 425 ft. (50 ft. in front of the pustless zone and 275 ft. behind) being strewn with coal dust at the rate of 1 lb. per linear foot. But since the action of the ventilating current, which is drawn through the gallery 7 seconds before ignition, is to draw dust towards the return ; while the concussion wave from the cannon used as igniter projects dust towards the downcast, the whole length of 425 ft. can be regarded as being strewn with dust at the time that the explosion started. This experiment will not, of course, compare exactly with Nos. 54 and 53 as regards the quantity of dust per linear foot, but it serves nevertheless to show the increase in pressure with increased distance of travel of the explosion.

Thus, the maximum pressures recorded were as follows :—

| Experiment. | Manometer. | Distance from point of ignition. | Maximum pressure. |
|---|---|---|---|
| | | Feet. | Pounds per square inch. |
| 54 | B | 125 | 35 |
| 53 | B | 150 | 38 |
| 54 | A | 225 | 50 |
| 53 | A | 250 | 65 |
| 62 | B | 275 | 43 |
| 62 | A | 375 | 92 |

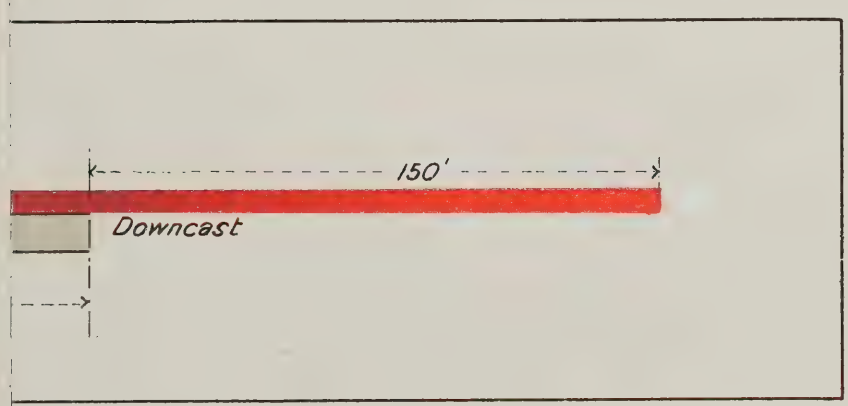
The only discordant figure in this table is the 43 lb. per square inch pressure recorded after 275 ft. of travel in Experiment No. 62. With this exception it will be seen that the pressure increases with the distance of travel of the explosion. As has already been stated, it is of the utmost importance to determine for what distance this increase would be maintained.

Curves showing the rate of development of the pressure from the time of ignition are given in Plates XV. to XX. It will be seen that in several cases the curve shows signs of rapid fluctuations at its summit. These fluctuations (shown in dotted line on the charts) are most probably due to the natural period of vibration of the manometer spring* which, when moving freely, has been found to be $\frac{1}{170}$ second,† so that the true curve of pressure is more nearly represented by the continuous line.

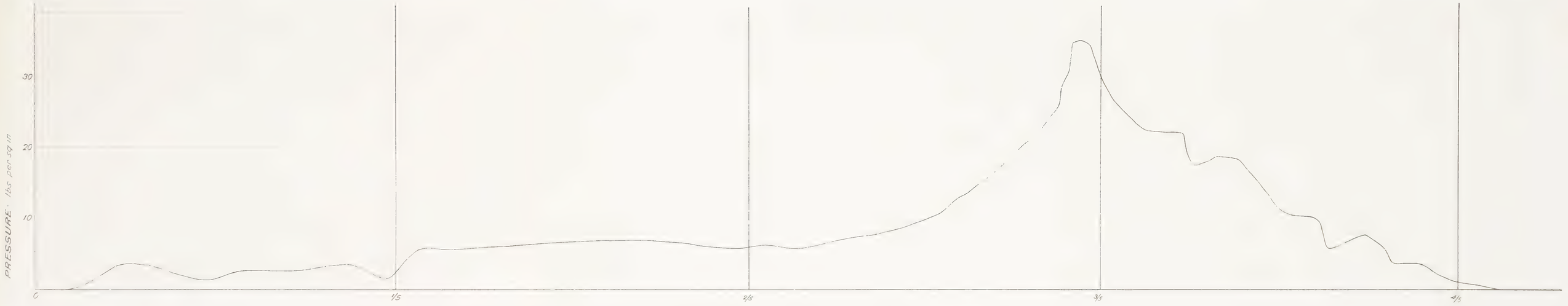
* In these experiments a heavy spring was employed on the manometer, a deflection of the scribing style of 1 mm. being equivalent to about 25 lb. per square inch pressure.

† One hundred and seventy complete vibrations per second.

# Plate XV.




ıg 125 Feet.




PRESSURE CURVE No 54 B.

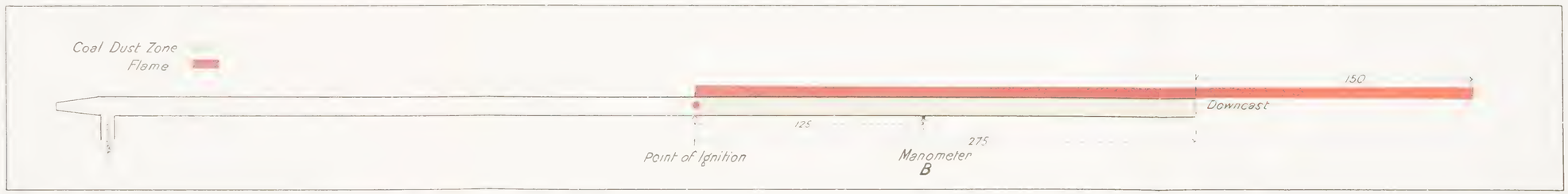
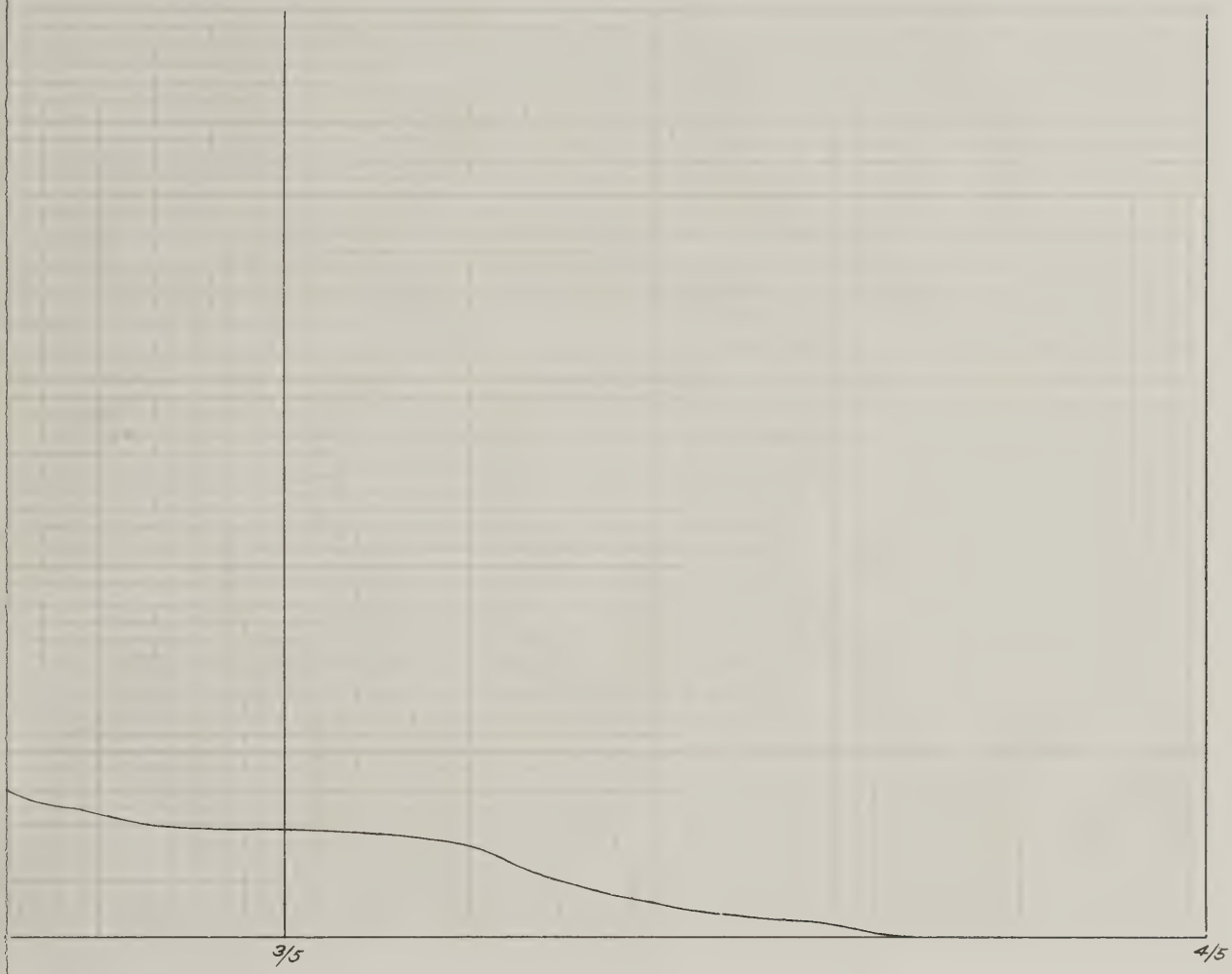
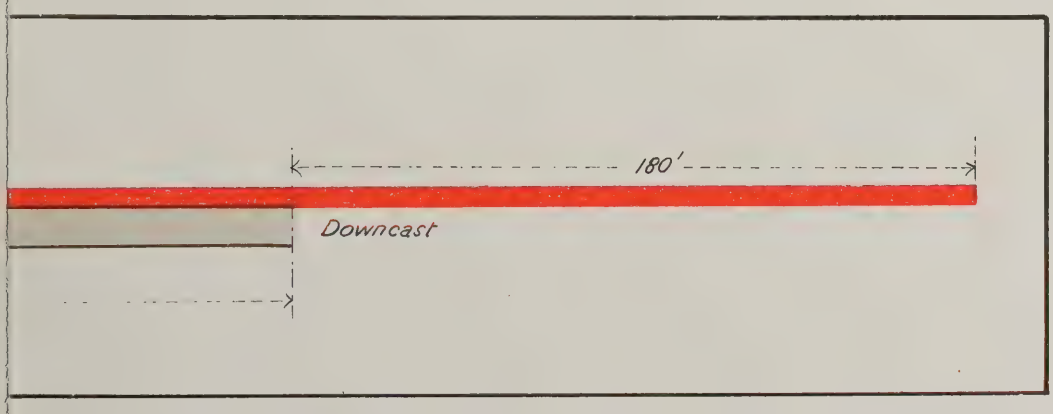


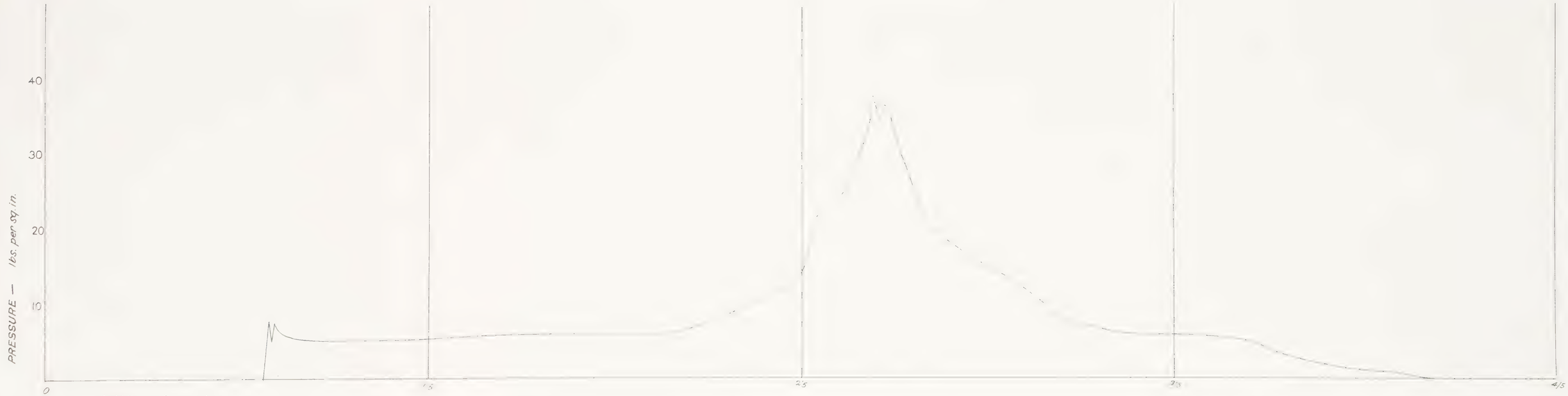

PLATE XV. PRESSURE DEVELOPED BY COAL DUST EXPLOSION AFTER TRAVELLING 125 FEET.

# Plate XVI.



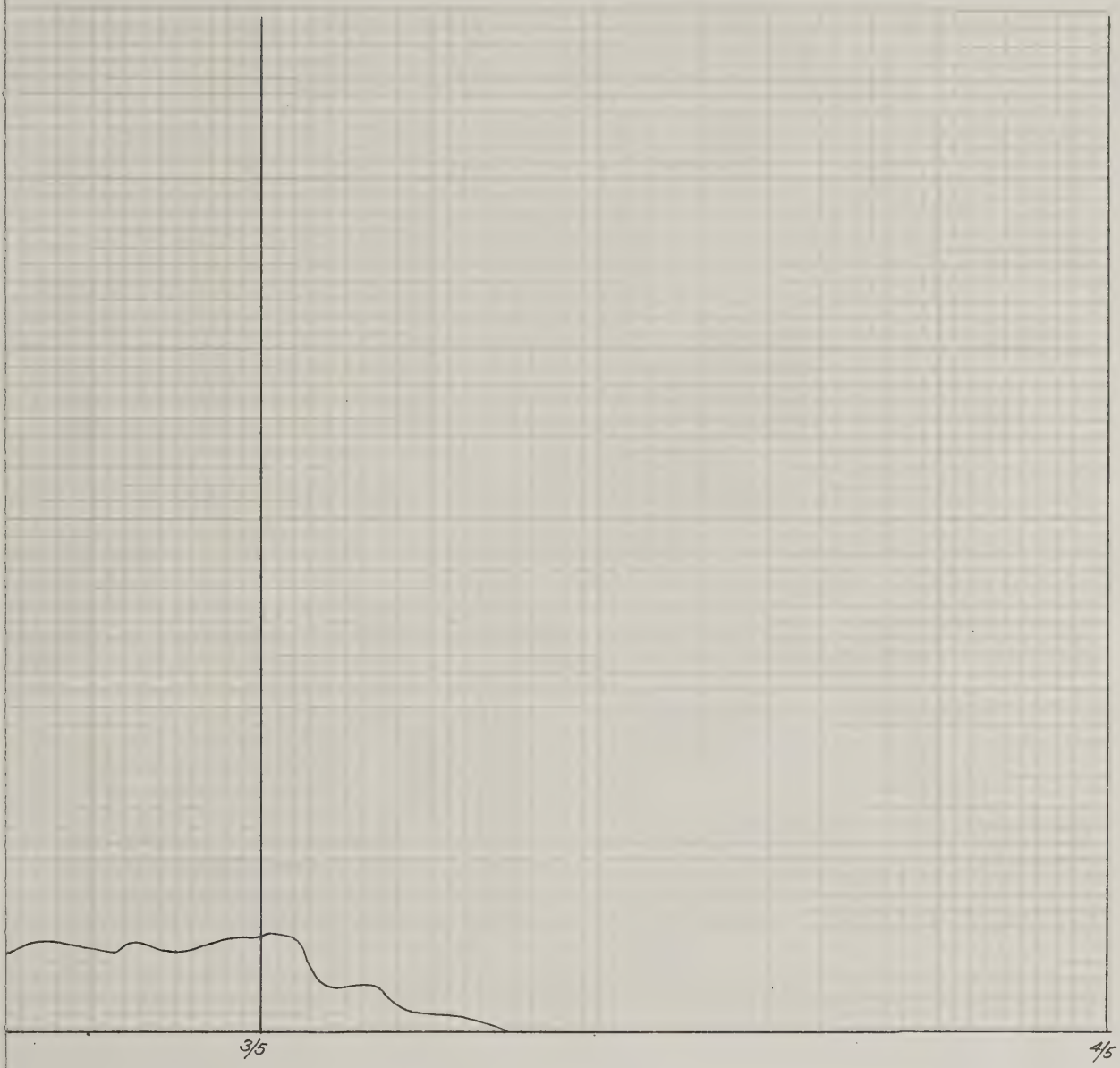

TER TRAVELLING 150 FEET.

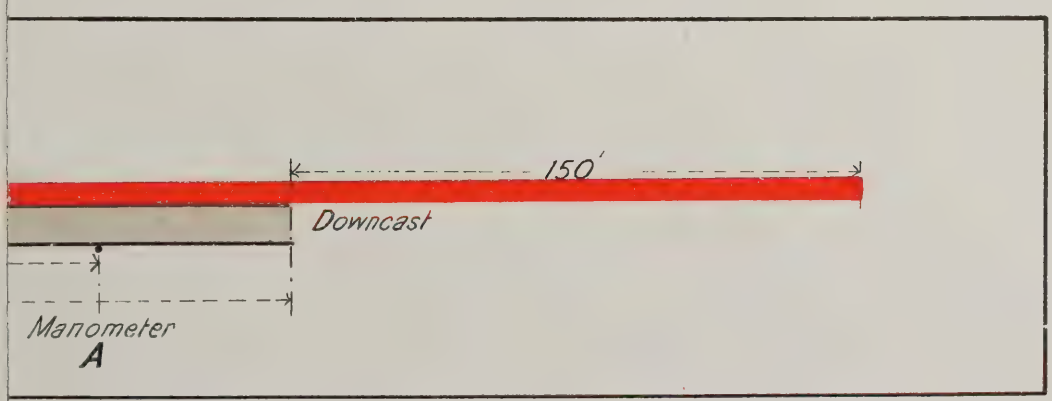



PRESSURE CURVE Nº 53 B.

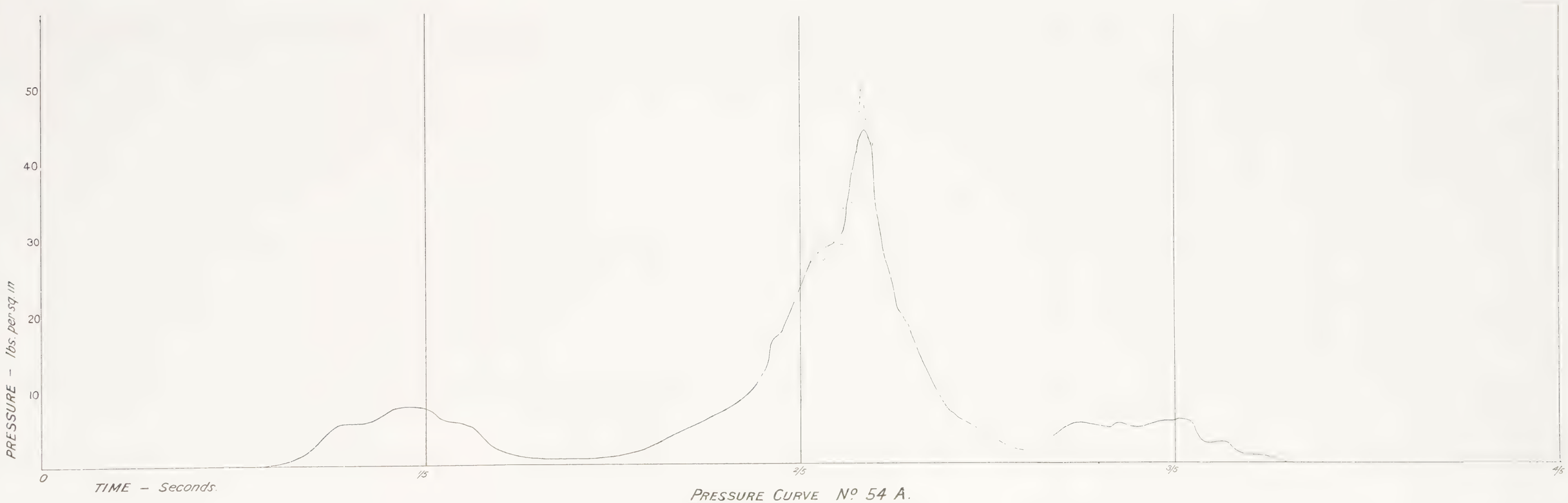
PLATE XVI. PRESSURE DEVELOPED BY A COAL DUST EXPLOSION AFTER TRAVELLING 150 FEET.

# Plate XVII.




## ER TRAVELLING 225 FEET.




PRESSURE CURVE Nº 54 A.

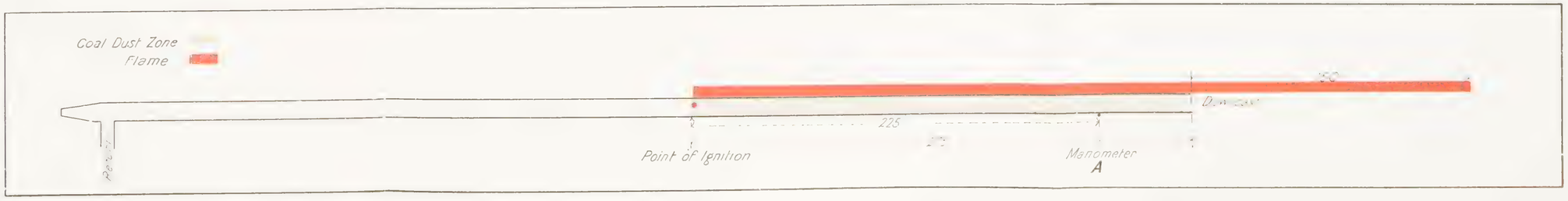
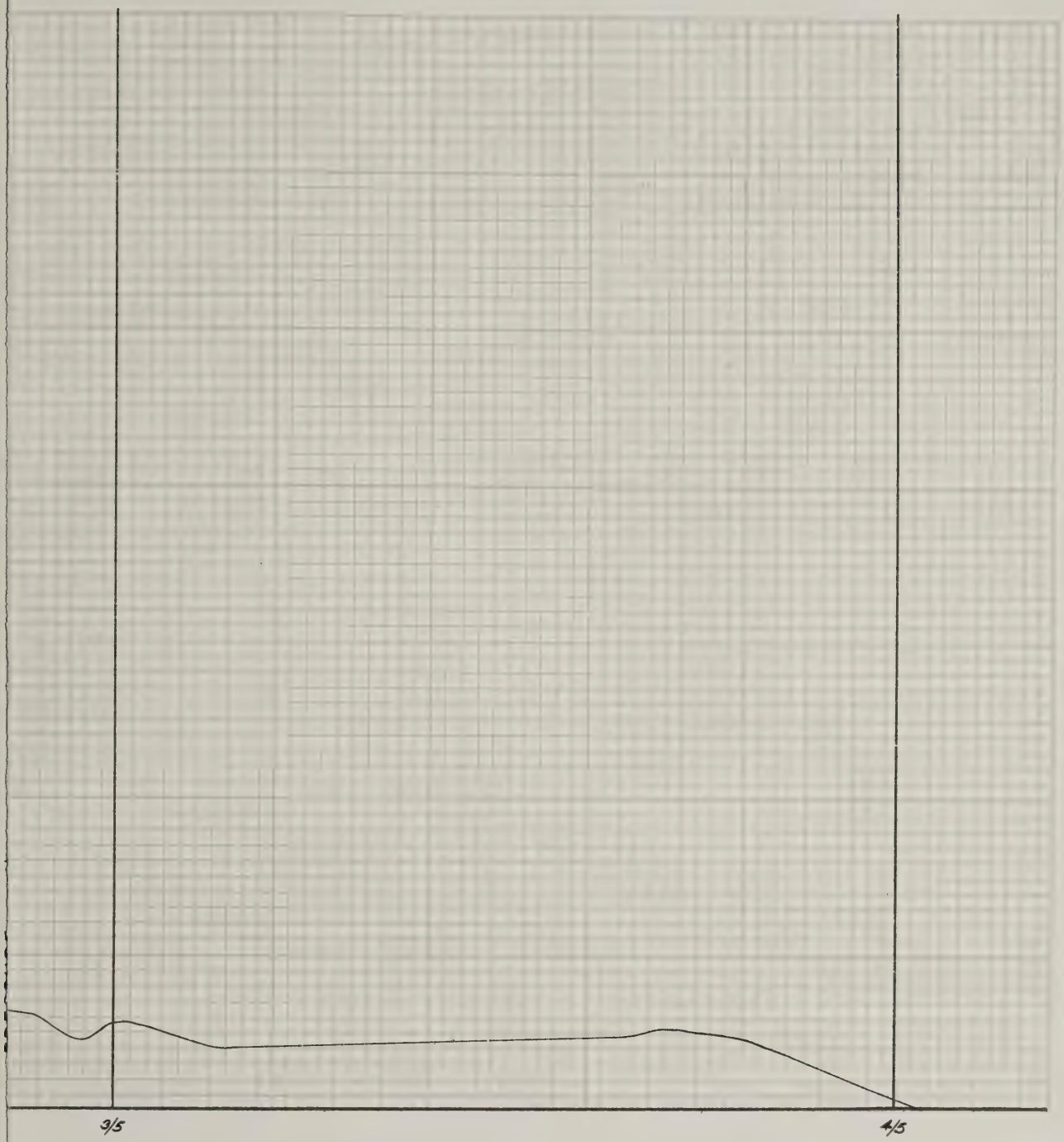
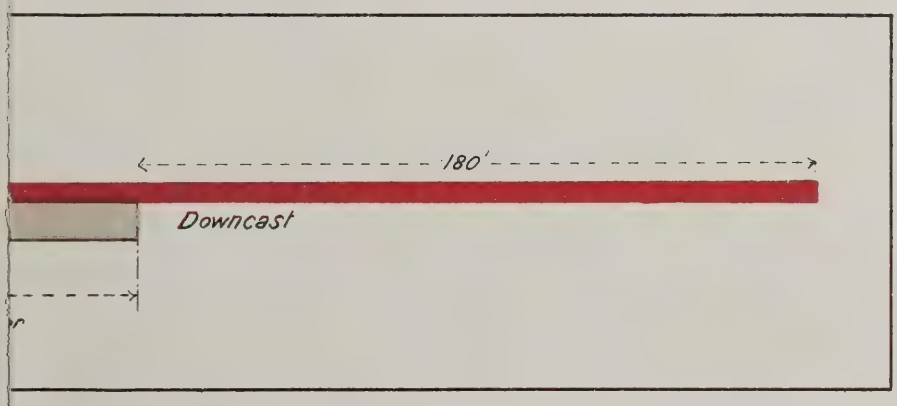



PLATE XVII. PRESSURE DEVELOPED BY A COAL DUST EXPLOSION AFTER TRAVELLING 225 FEET.

# PLATE XVIII.




LLING 250 FEET.

PLATE XVIII.

PRESSURE CURVE. Nº 53. A.

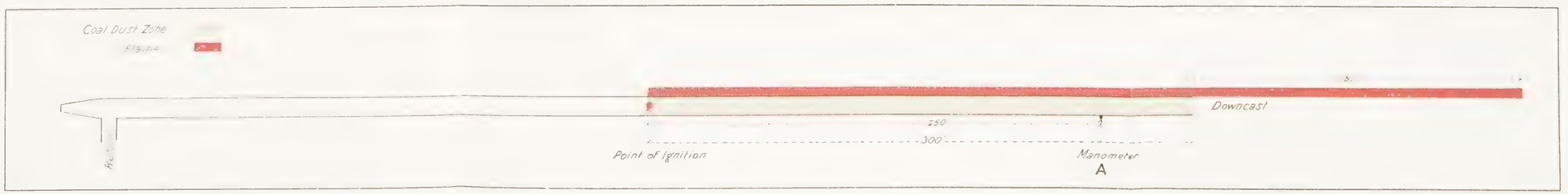
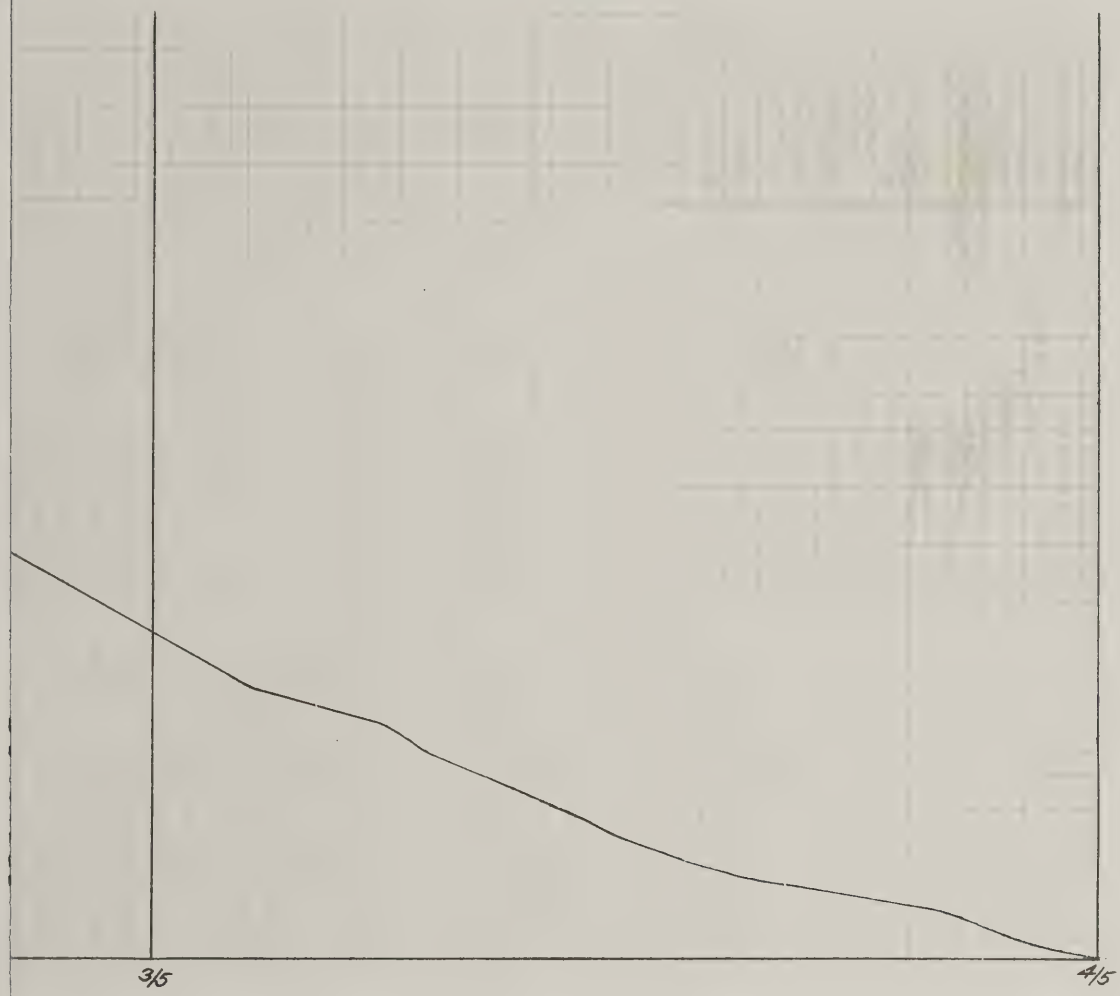
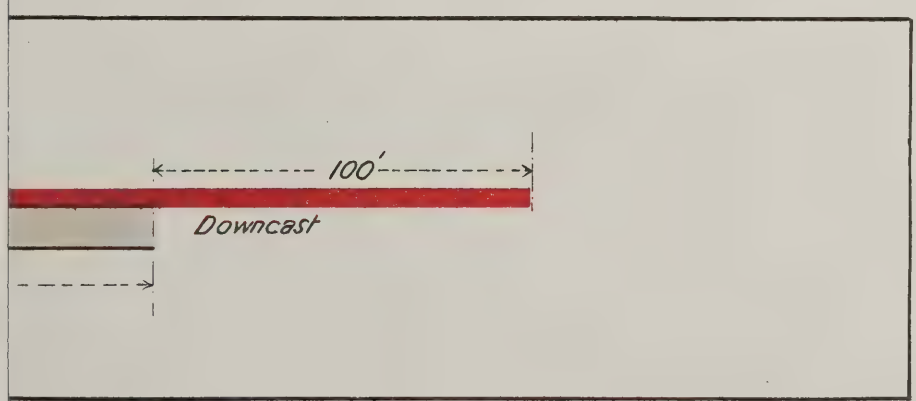


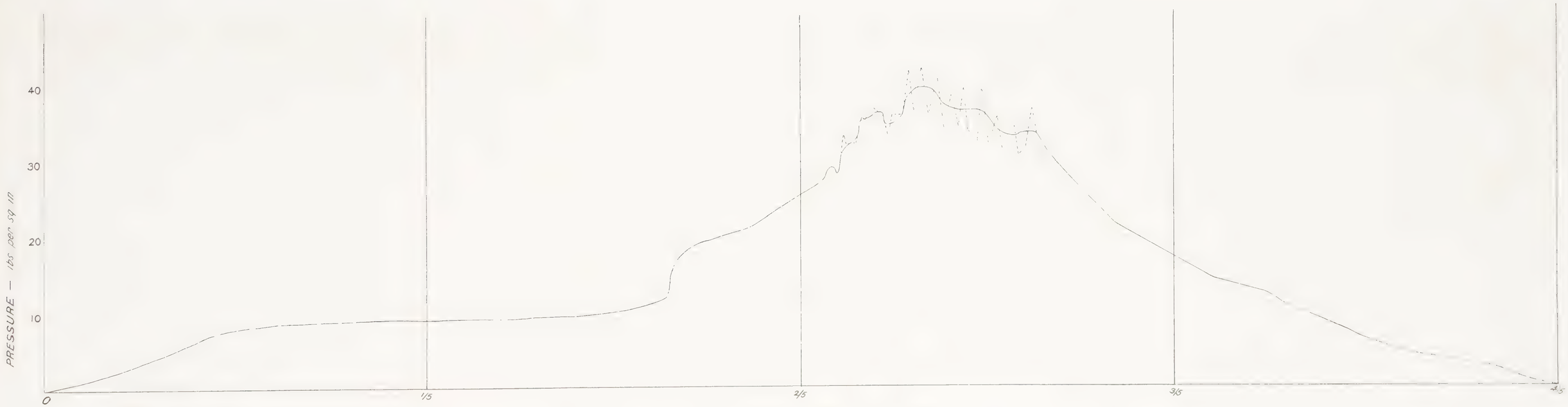

PLATE XVIII. PRESSURE DEVELOPED BY COAL DUST EXPLOSION AFTER TRAVELLING 250 FEET.

# PLATE XIX.




RAVELLING 275 FEET.




PRESSURE CURVE. Nº 62 B.

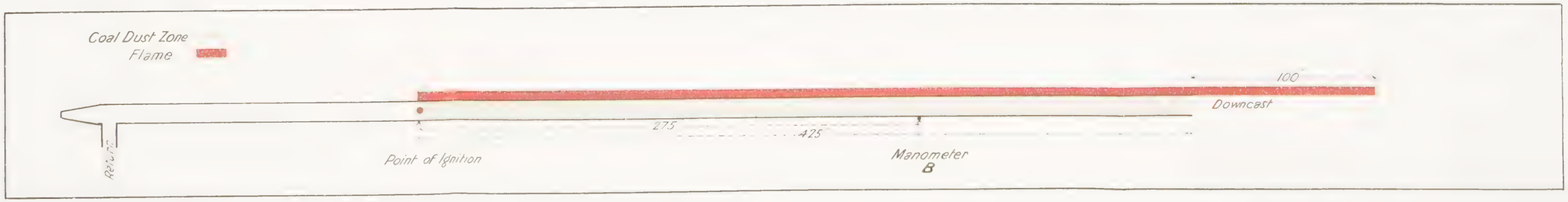



PLATE XIX. PRESSURE DEVELOPED BY A COAL DUST EXPLOSION AFTER TRAVELLING 275 FEET.

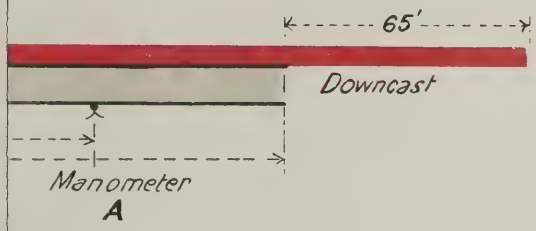
# PLATE XX.

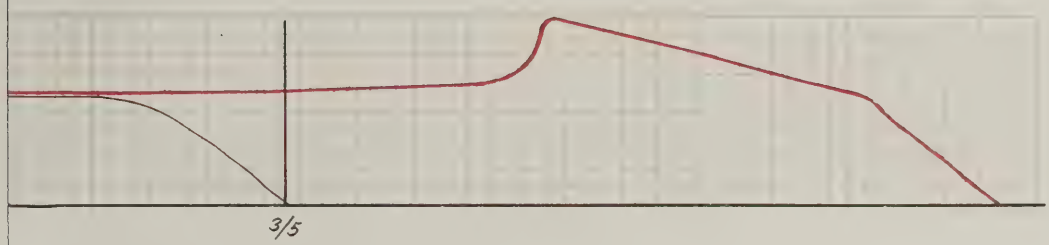
## ER TRAVELLING 375 FEET.

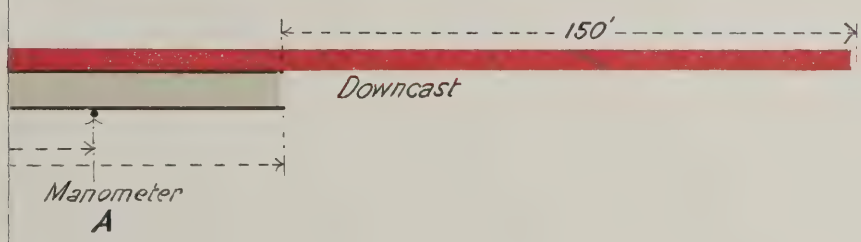
PLATE XX.

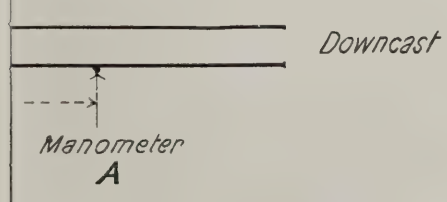
PLATE XX. PRESSURE DEVELOPED BY A COAL DUST EXPLOSION AFTER TRAVELLING 375 FEET.

# PLATE XXI.



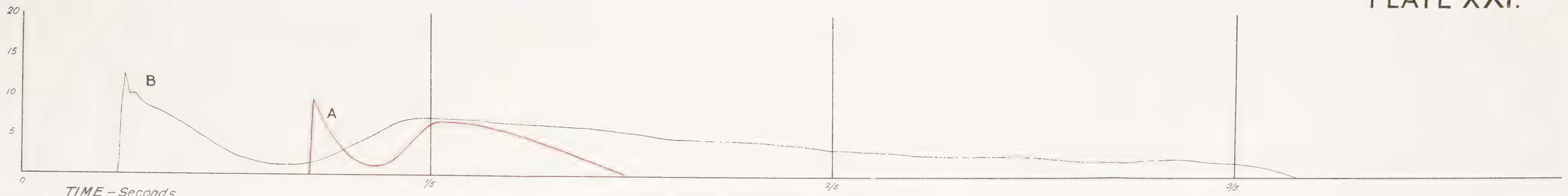



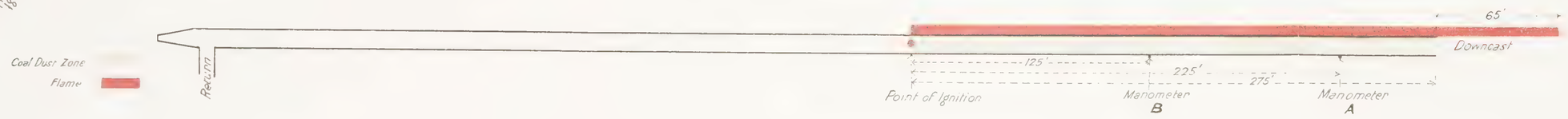


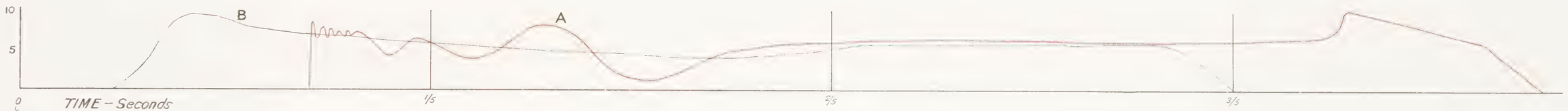

LEAR GALLERY.

PLATE XXI.

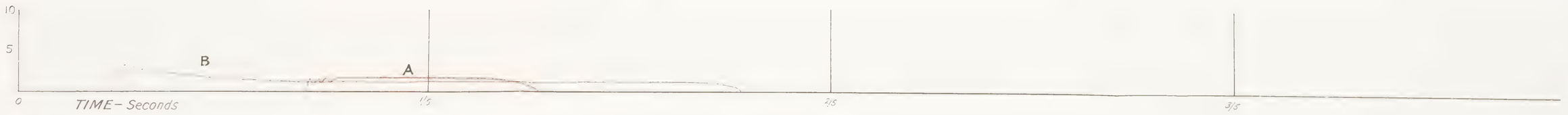



PRESSURE CURVES Nos 50 A and B.




PRESSURE CURVES. Nos 51 A and B.




PRESSURE CURVES. Cannon only A and B. (Curves Nos CA and CB)

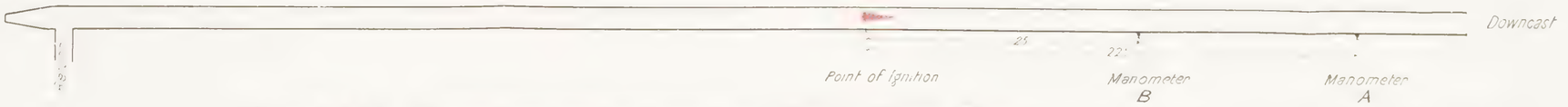
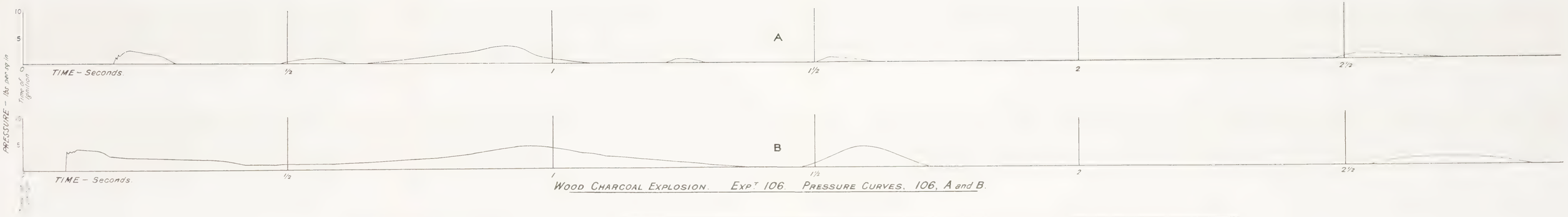
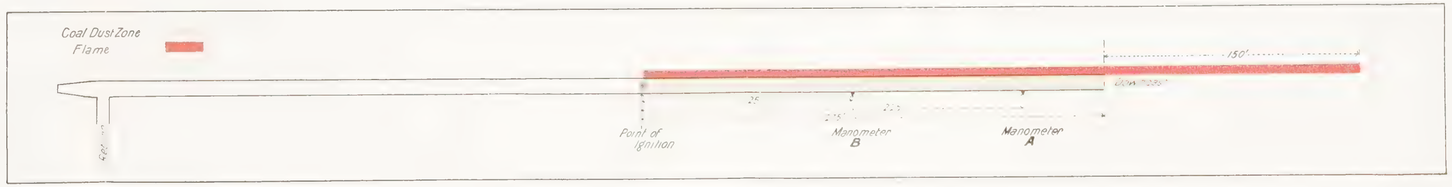



PLATE XXI. PRESSURE DEVELOPED BY COAL DUST EXPLOSIONS. USING A CLEAR GALLERY.




WOOD CHARCOAL EXPLOSION. EXP.T 106. PRESSURE CURVES. 106, A and B.




## PLATE XXII. PRESSURE DEVELOPED BY WOOD CHARCOAL EXPLOSION.

TABLE IV.

SERIES I.

EXPERIMENTS WITH THE INTAKE SET WITH PROPS AND BARS EVERY 9 FT. FROM THE DOWNCAST TO THE POINT OF IGNITION.

Ignition was effected by the firing of a charge of 24 oz. of blasting powder from a cannon stemmed with 8 in. of dry clay.

An air current of 50,000 cubic feet per minute was drawn through the downcast at the time of explosion.

Length of intake = 600 ft. Sectional area = 41 square feet.
Length of return = 295 ft. Sectional area = 28 square feet.
Quantity of Silkstone coal used, 1 lb. per linear foot = 0·4 oz. per cubic foot.

| Experiment No. | 54 | 53 | 62 |
|---|---|---|---|
| 1909 | June 30th | June 24th | July 20th |
| *Experimental Conditions:—* | | | |
| Length of coal dust zone (from downcast to point of ignition). | 275 ft. | 300 ft. | *See* text |
| Position of igniter (measured from downcast) | 275 ft. | 300 ft. | 425 ft. |
| Position of manometers (measured from point of ignition):— | | | |
| A | 225 ft. | 250 ft. | 375 ft. |
| B | 125 ft. | 150 ft. | 275 ft. |
| *Coal Dust (Altofts Silkstone):—* | | | |
| Analysis— | | | |
| Moisture, per cent. | 2·46 | 2·47 | 3·22 |
| Per cent. of dry coal: Volatile matter | 33·50 | 33·40 | 33·56 |
| Per cent. of dry coal: Fixed carbon | 62·22 | 61·46 | 62·29 |
| Per cent. of dry coal: Ash | 4·28 | 5·14 | 4·15 |
| Fineness— | | | |
| Remaining on 100 mesh | 5·00 per cent. | 6·50 per cent. | 5·00 per cent. |
| Through 100 on 150 | 8·00 | 9·50 | 11·50 |
| „ 150 on 200 | 3·50 | 3·75 | 2·50 |
| „ 200 on 240 | 7·50 | 8·00 | 7·50 |
| „ 240 and finer | 76·00 | 72·25 | 73·50 |
| *Meteorological Conditions:—* | | | |
| Barometric pressure | 29·94 in. | 29·47 in. | 29·70 in. |
| Temperature inside gallery:— | | | |
| Before explosion— | | | |
| Dry bulb | 62 degs. F. | 64 degs. F. | 63 degs. F. |
| Wet bulb | 55 | 58 | 57 |
| Humidity, per cent. of saturation | 62 | 67 | 67 |
| After explosion— | | | |
| Dry bulb | 63 | 69 | 63 |
| Wet bulb | 56 | 63 | 56 |
| Humidity, per cent. of saturation | 63 | 68 | 63 |
| Direction of wind | N.E. | N.E. | N.E. |
| General state of weather | Fine | Fine | Fine |
| Time of experiment | 2.10 p.m. | 1.10 p.m. | 5.30 p.m. |

The sudden change in pressure that sometimes occurs after a comparatively slow development is well shown in the case of No. 62 A, where a change takes place from 40 to 90 pounds per square inch in a time interval of $\frac{1}{100}$ second. A determination of the velocity of the explosion (Experiment No. 62) between one contact breaker 175 ft. from the point of ignition and a second at manometer A (a

distance of 200 ft.) gave a value of 2,014 ft. per second. This represents the *mean* speed for 200 ft. of travel, and it is not suggested that the velocity at which the explosion was travelling was uniform over the whole distance; later experiments, indeed, having shown that such is far from being the case. Assuming, however, that 2,014 ft. per second was the speed at the time that the pressure record shows a change from 40 to 90 pounds per square inch, this change must have occurred over a distance of 20 ft. only, since $\frac{1}{100}$ second was the time occupied.

In Experiment No. 53, on the other hand, the velocity between the point of ignition and a point 275 ft. distant was 475 ft. per second. This measurement, however, includes the whole length from the very beginning of the explosion, while many determinations have shown that the velocity at which the explosion travels for the first 175 ft. is only about 350 ft. per second, so that the speed during the next 100 ft. was about 1,300 ft. per second.

## 2. The Influence of Obstructions.

In the experiments just described the intake of the gallery, from the downcast to the point of ignition, was set with props and bars every 9 ft. To show the marked influence of these obstructions in causing the explosion to be propagated *with greater violence*, the following series of experiments is recorded in which a clear gallery was used.

### SERIES II.

#### Experiments with the Gallery Clear of Obstructions.

The two manometers were fixed as before at distances of 50 ft. and 150 ft. from the downcast, and the positions of the point of ignition were as follows :—

| Experiment No. | Position of point of ignition. |
|---|---|
| 50 | 275 ft. from downcast |
| 51 | 300 „ „ „ |
| 110 | 425 „ „ „ |

so that, as in the previous series, the manometers recorded the development of the explosion over distances of 125, 150, 225, 250, 275, and 375 feet.

The experiments are, therefore, strictly comparable with the previous series as regards distance of travel of the explosion. The dust was laid on the floor and on shelves along the sides of the gallery at the rate of 1 lb. per linear foot. The same means of ignition was employed, and the same ventilating current; in fact, as far as possible, the conditions of experiment were identical in the two series, with the exception that in this second series no props or bars were set. (*See* Table V).

The maximum pressures recorded were as follows :—

| Experiment. | Manometer. | Distance from point of ignition. | Maximum pressure. |
|---|---|---|---|
| | | Feet. | Pounds per square inch. |
| 50 | B | 125 | 11·9 |
| 51 | B | 150 | 9·8 |
| 50 | A | 225 | 8·75 |
| 51 | A | 250 | 8·3 |
| 110 | B | 275 | 8·5 |
| 110 | A | 375 | 9·2 |

TABLE V.

SERIES II.

Experiments with the Intake Clear of all Obstruction.

Ignition was effected by the firing of a charge of 24 oz. of blasting powder from a cannon stemmed with 8 in. of dry clay.

An air current of 50,000 cubic feet per minute was drawn through the downcast at the time of explosion.

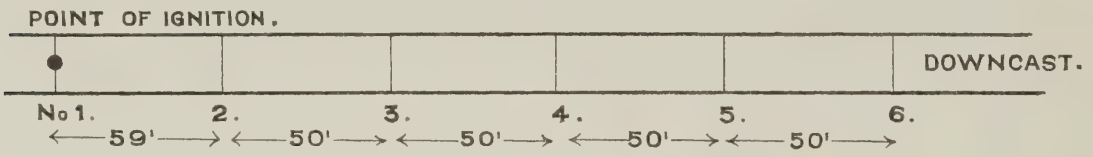
Length of intake = 600 ft. Sectional area = 41 square feet.
Length of return = 295 ft. Sectional area = 28 square feet.
Quantity of Silkstone coal used 1 lb. per linear foot = 0·4 oz. per cubic foot.

| Experiment No. | 50 | 51 | 110 |
|---|---|---|---|
| 1909 | June 17th | June 18th | October 8th |
| *Experimental Conditions:—* | | | |
| Length of coal dust zone (from downcast to point of ignition) | 275 ft. | 300 ft. | 425 ft. |
| Position of igniter (measured from downcast) | 275 ft. | 300 ft. | 425 ft. |
| Position of manometers (measured from point of ignition):— | | | |
| A | 225 ft. | 250 ft. | 375 ft. |
| B | 125 ft. | 150 ft. | 275 ft. |
| *Coal Dust (Altofts Silkstone):—* | | | |
| Analysis— | | | |
| Moisture, per cent. | 2·10 | 2·80 | 2·50 |
| Per cent. of dry coal: Volatile matter | 33·46 | 33·45 | 33·52 |
| Per cent. of dry coal: Fixed carbon | 60·92 | 61·85 | 61·63 |
| Per cent. of dry coal: Ash | 5·62 | 4·70 | 4·85 |
| Fineness— | | | |
| Remaining on 100 mesh | 1·50 per cent. | 2·00 per cent. | 1·80 per cent. |
| Through 100 on 150 | 9·50 | 9·50 | 9·20 |
| „ 150 on 200 | 2·00 | 4·00 | 2·50 |
| „ 200 on 240 | 11·00 | 11·00 | 10·80 |
| „ 240 and finer | 76·00 | 73·50 | 75·70 |
| *Meteorological Conditions:—* | | | |
| Barometric pressure | 30·27 in. | 30·32 in. | 30·10 in. |
| Temperature inside gallery:— | | | |
| Before explosion— | | | |
| Dry bulb | 77 degs. F. | 69 degs. F. | 59 degs. F. |
| Wet bulb | 63 | 59 | 54 |
| Humidity per cent. of saturation | 44 | 53 | 71 |
| After explosion— | | | |
| Dry bulb | 84 | 76 | 65 |
| Wet bulb | 63 | 63 | 62 |
| Humidity per cent. of saturation | 30 | 46 | 83 |
| Direction of wind | N.W. | N.W. | N.W. |
| General state of weather | Fine | Cloudy | Fair |
| Time of experiment | 12.45 p.m. | 6.10 p.m. | 1 p.m. |

The pressure charts, reproduced on Plate XXI., when compared with the charts of Experiments Nos. 54, 53 and 62, show the difference still more clearly. These records were obtained by using a light spring on the manometers, its natural period of vibration being $\frac{1}{80}$ second, and a deflection of the scribing style of 1 mm. being equivalent to about 5 lb. per square inch pressure. They are therefore able to show the pressure due to the firing of the charge of blasting powder used to cause ignition, of which the records obtained from the heavy springs rarely give

any indication. In order to be able to judge to what extent the curve traced is due to the pressure caused by the cannon shot, curves Nos. C A and C B have been reproduced at the bottom of Plate XXI. These curves were obtained by firing the cannon, charged with 24 oz. of blasting powder, at a point 275 ft. from the downcast, the manometers being 125 and 225 feet away respectively.

The speed at which the flame travelled along the gallery was also much slower than when obstructions were present. Thus, in Experiment No. 110, a record of the velocity between six points was obtained, the position of the points being as shown in the accompanying diagram :—




The velocities recorded were as follows :—

| | | | | |
|---|---|---|---|---|
| Between | 1 (point of ignition) | and | 2 = 39·7 | ft. per second. |
| ,, | 2 | ,, | 3 = 252·5 | ,, |
| ,, | 3 | ,, | 4 = 72·5 | ,, |
| ,, | 4 | ,, | 5 = 119·0 | ,, |
| ,, | 5 | ,, | 6 = 222·6 | ,, |

The reason for the high pressures, and high velocities, obtained when props and bars are present, cannot be definitely stated without further experiment.

It would appear most likely that each prop, by offering a certain amount of surface at right angles to the direction of movement of the explosion, enables a compression wave to be formed, thereby causing heat to be generated and combustion of the dust to be more rapid.*

Another possible explanation is, that each prop presents a surface upon which coal dust can be driven by the advancing column of heated gases and distilled, the coal gas produced then propagating the explosion with greater violence. Such a distillation would, however, take an appreciable time compared with the rate at which the explosion is travelling, so that it is very doubtful whether the actual propagation of the explosion occurs by any other means than combustion of the dust *as a whole* ; distillation may, and, in fact, does, occur, but there is more reason to believe that it is effected by the heated products of combustion, and is *subsequent to* the passage of the explosion.

A third explanation can be found in the mechanical action of the props in forming eddies, and enabling a better mixing of the dust and air to take place than would otherwise occur.

### 3. The Explosion of Wood-charcoal Dust and Air.

It is generally maintained that there are two chief processes by which a coal dust explosion can be propagated. On the one hand, the dust, when suspended in a sufficiently finely divided state in the air, acts as a kind of coarse gas mixture ; in other words, the aggregate of molecules contained in the one particle of dust will correspond to the single molecule which takes part in an explosion of a combustible gas, the heat-energy necessary for propagation of the explosion being obtained by

* Dixon has shown (*Phil. Trans.* 1903, vol. 200 A) that a slight obstruction in the tubes he used when examining the movement of the flame during explosion in gases was able to cause a compression wave and accelerated the formation of the detonation-wave.

combustion of the dust as a whole. If this is so, any finely-divided dust, if capable of being burnt, is also capable of causing an explosion.

On the other hand, in view of the fact that coal so readily yields combustible gas when heated to a low temperature, it has been assumed that the sole reason why an explosion takes place in coal dust and air is that the initial heat which causes ignition of the dust also distils some gas from the dust, and that it is the burning of this gas by a further quantity of air that supplies energy and admits of propagation of explosive combustion.

There is no doubt, as experiments (one of which is recorded below) prove, that a finely-divided carbonaceous dust, incapable of giving off combustible gas on heating, will form an explosive mixture with air.

The time that must be allowed for distillation of gas from coal dust to take place seems to preclude the possibility of that gas playing any important part separately from the dust in the propagation of the explosion. Moreover, the decomposition of coal, yielding inflammable gases, *absorbs* energy.

Preliminary experiments, made in December 1908, had shown that there was no difficulty in obtaining propagation of flame through a cloud of wood-charcoal dust in air.

A glass tube 4 in. in diameter and 20 ft. long was employed (fig. 85). An air supply from a Roots blower was allowed to pass through a layer of wood-charcoal dust, about 6 inches deep, before travelling through the explosion tube. Ignition was effected by means of a small blow-pipe jet, and the flame travelled, with the air current, the whole length of the tube, and issued with considerable force from the other end.*

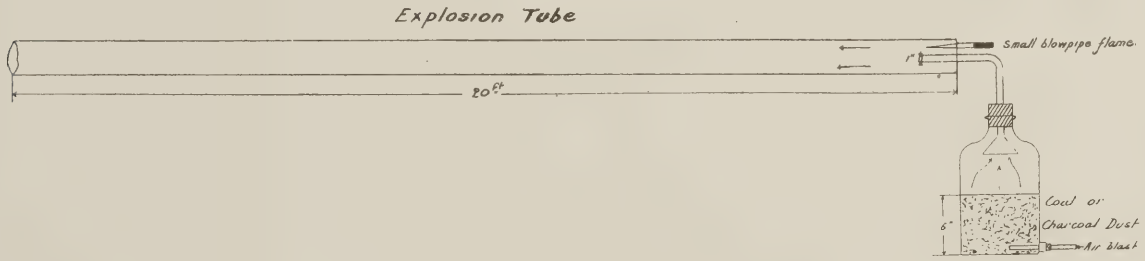



Fig. 85.

*Experiment No.* 106, *October 1st*, 1909.—With the exception that pulverised wood charcoal was substituted for the coal dust, this experiment was carried out in a similar manner to those previously described.

The charcoal was laid on the floor and on shelves along the gallery for a distance of 275 ft. from the downcast at the rate of 1 lb. per linear foot.

Props and bars were set along the gallery, 9 ft. apart, from the downcast to the point of ignition.

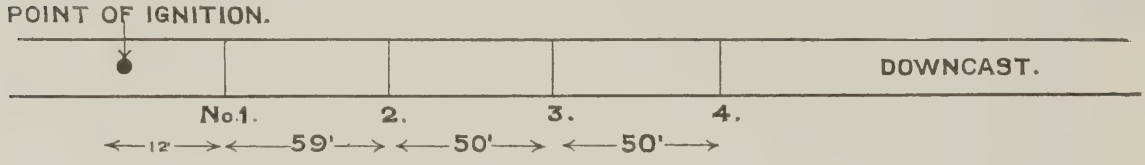
Ignition was effected by the firing of a charge of 24 oz. of blasting powder from a cannon stemmed with 8 in. of dry clay.

Two successive volumes of flame shot out from the downcast, followed by a marked back suction. The appearance of the flame was quite distinct from that

* Experiments carried out in the laboratory in this way give a valuable indication of the relative inflammability of dusts from different coals. Preliminary tests, made before the experiments with wood-charcoal, showed that the denser the coal the more finely it must be pulverised in order to allow a flame to be propagated through the dust-cloud.

observed in the coal dust explosions, being apparently more intense and accompanied by much scintillation. The report of the explosion did not appear to be quite so loud as with coal dust, but the flame was projected 150 ft. from the downcast end, and a few only of the props in the intake remained standing.

The rate of propagation of the flame was quite slow ; a determination of the velocity between four points from the point of ignition gave the following results :—




| | | Feet per second. |
|---|---|---|
| Between No. 1. (12 ft. from point of ignition) | and No. 2 | = 116·5 |
| „ No. 2 | „ No. 3 | = 215·2 |
| „ No. 3 | „ No. 4 | = 170·8 |

The fluctuation in the speed of propagation is also shown in the pressure curves (Plate XXII.), where it will be seen that the total length of duration of pressure from the time of ignition was 2 seconds, while the manner in which the pressure dies out and appears again after a short interval is clearly shown.

# THE EXPLOSION OF WOOD CHARCOAL.

## EXPERIMENT No. 106.

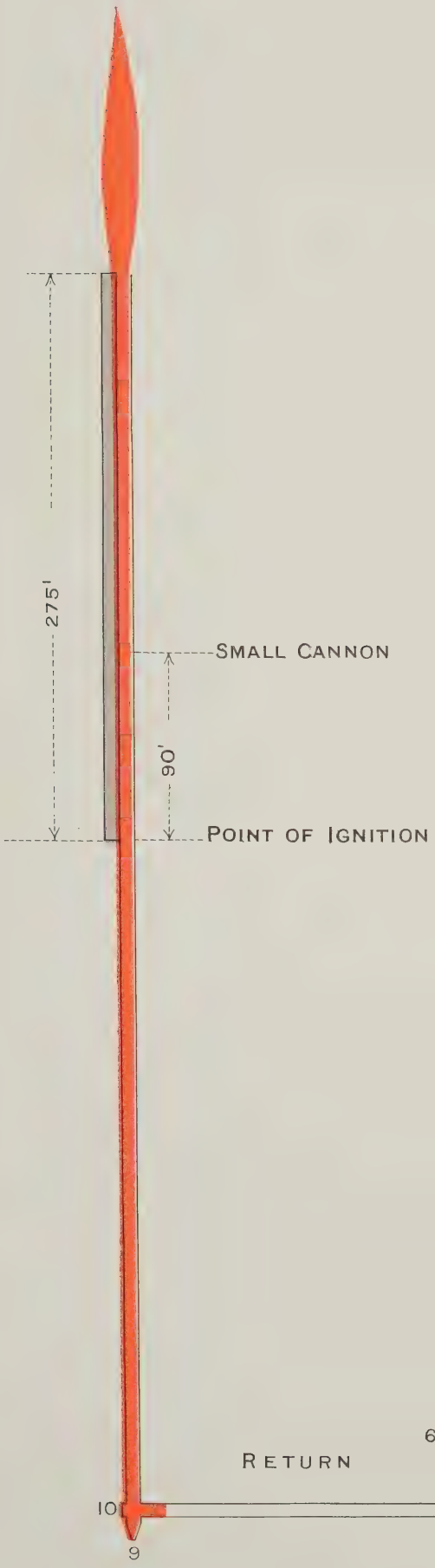
# EXPERIMENT No. 106.

OCTOBER 1st, 1909.

| | |
|---|---|
| Length of Intake ... ... ... | 600 ft. |
| Sectional Area of Intake ... | 41 sq. ft. |
| Length of Return... ... ... | 295 ft. |
| Sectional Area of Return ... | 28 sq. ft. |

Charcoal Dust Zone, 275 ft., thus

Flame ... ... 762 ft., thus




## PLAN.

Scale: $\frac{1}{960}$ or 80 ft. equals One Inch.

## METEOROLOGICAL CONDITIONS.

| | |
|---|---|
| Barometer ... .. ... ... | 28·75 in. |
| Thermometer, External Wet, 53° F. | Dry, 54° F. |
| ,, Internal ,, 55° F. | ,, 61° F. |
| Humidity, External ... ... ... | 93 % |
| ,, Internal ... ... ... | 67 % |
| Direction of Wind .. ... ... | South-East. |
| Velocity of Wind ... ... ... | 3 m. per hour. |
| General State of Weather ... ... (at time of Experiment) | Very dull & damp. 11·20 a.m. |

***NOTE.—Relief valves shown by numbers 1, 2, 3, etc.***

## EXPERIMENT No. 106.

### Main Object of Experiment.

To test whether wood charcoal dust would propagate explosion when ignited after being raised as a cloud in air.

### Experimental Conditions.

Position of igniter, 275 ft. from downcast.
Quantity of air, 64,000 cubic feet per minute.
Velocity of air, 1,560 ft. per minute.
Quantity of dust, 1 lb. per linear foot = 0·4 oz. per cubic foot.
Large cannon, charge 24 oz., clay stemming 8 in.
Small cannon, charge 4 oz., clay stemming 4 in.
Number of sets of timber in intake, fixed every 9 ft. from downcast to point of ignition.

### Fineness of Dust.

| | Per cent. |
|---|---|
| Remaining on 100 mesh ..... | 7·0 |
| Through 100 on 150 ..... | 8·5 |
| ,, 150 on 200 ..... | 2·5 |
| ,, 200 on 240 ..... | 5·0 |
| ,, 240 and finer..... | 78·0 |

### Result.

Two volumes of flame shot out from the downcast followed by a marked back suction.
Total length of flame sent out from downcast = 150 ft.
The flame penetrated 12 ft. into the return.

To face page 164.

Fig. 86.—The Flame projected from the Downcast, due to the Explosion of Wood Charcoal.

Fig. 87.—The Flame from the Explosion of Wood Charcoal. This photograph was taken as nearly as possible one second later than that shown above.

In addition to these three outstanding features of the experiments there are many points of great interest that have been observed but which require confirmation before any definite statement is made with regard to them.

## The Products of Combustion.

All the samples of the products of combustion obtained in the experiments up to date have been trapped after the explosion has passed.

The position of the sampling bottle and its time of action relative to the passage of the explosion were as follows :—

The sampling bottle was placed 75 ft. from the downcast, and the contact maker which actuated it 5 ft. from the downcast. With this arrangement the sample was trapped after the explosion had travelled 70 ft. past the sampler, so that, knowing the speed of propagation of the explosion between the sampler and the contact maker, the time that the sample was taken after the explosion had passed could be calculated. Further, the sampler was set so as to remain open to the gallery for $\frac{1}{10}$ second.

*Experiment No.* 91.—The velocity of the explosion between the sampler and the contact maker was 1,400 ft. per second, so that the sample was taken about $\frac{1}{20}$ second after the explosion had passed.

The sample contained :—

| | | | |
|---|---|---|---|
| Carbon dioxide | 11·25 per cent. | = 12·65 per cent. | of pure afterdamp |
| Carbon monoxide | 8·15 ,, | = 9·20 ,, | ,, |
| Oxygen | 1·15 ,, | | |
| Hydrogen | 2·75 ,, | | |
| Methane | 2·95 ,, | | |
| Nitrogen | 73·75 ,, | = 78·15 ,, | ,, |

and therefore consisted of nearly pure afterdamp.

*Experiment No.* 114.—The velocity of the explosion between the sampler and the contact maker was 700 ft. per second, so that the sample was taken about $\frac{1}{10}$ second after the explosion had passed.

The sample contained :—

| | | | |
|---|---|---|---|
| Carbon dioxide | 8·75 per cent. | = 13·20 per cent. | of pure afterdamp |
| Carbon monoxide | 5·75 ,, | = 8·65 ,, | ,, |
| Oxygen | 6 20 ,, | | |
| Hydrogen | 2·25 ,, | | |
| Methane | 1·80 ,, | | |
| Nitrogen | 75·25 ,, | = 78·15 ,, | ,, |

Calculations from the gas analysis No. 91 show that 18·10 per cent. of the oxygen of the air that took part in the combustion appears in the gaseous products as carbon compounds ; the remaining 2·85 per cent. must therefore have combined with hydrogen to form steam and been condensed, so that the ratio between the oxygen utilised to burn carbon to that used to burn hydrogen is 6·35 : 1.

Calculation from the ultimate analysis of the Silkstone coal used in the experiment shows that on complete combustion the oxygen of the air should be

distributed between the carbon and the hydrogen in the coal in the proportion 6·3 : 1 ; while for partial combustion (to the extent shown in Explosion No. 91, with the formation of 8·16 per cent. of carbon monoxide), the ratio would be lower.

There is therefore no evidence of the *separate* combustion of volatile constituents of the coal during the explosion, for in that case the ratio between the oxygen present as carbon compounds to that present as steam should certainly be less than 6·3 : 1, since the volatile constituents contain a larger percentage of hydrogen than the coal as a whole. The presence of 2·95 per cent. of methane and 2·75 per cent. of hydrogen is occasioned by distillation *subsequent to* the passage of the flame, while it is quite possible that part at least of the carbon monoxide may arise from the reaction $CO_2 + C = 2CO$ occurring between the products of combustion of the explosion and excess of coal dust.*

A sample taken at the moment the explosion passes should consist of pure afterdamp, *i.e.*, all the oxygen should have disappeared. The 1·13 per cent. of oxygen occurring $\frac{1}{20}$ second after the explosion has passed (Experiment No. 91) and the 6·20 per cent. $\frac{1}{10}$ second after (Experiment No. 114), give some idea of the rate at which dilution of the afterdamp occurs due to air rushing into the gallery to fill up the vacuum caused by the cooling of products of combustion. But it must be noted that the two explosions are not comparable as regards speed of propagation and pressure developed.

* *See* page 131.

## NOTE IV.

Dr. J. S. Haldane has kindly contributed the following note regarding the afterdamp analyses :—

" One of the most important results of the analyses is the fact that as much as 8·62 and 8·17 per cent. " of carbon monoxide was present in the crude undiluted afterdamp.* If this afterdamp were diluted to a " sixth with pure air the resulting mixture would contain about 1·4 per cent. of carbon monoxide and " 17·4 per cent. of oxygen, and a lamp would just burn in it. The flame would show a distinct cap, as " about 2·3 per cent. of combustible gas (carbon monoxide, methane, and hydrogen) would be present. " The mixture would be extremely poisonous, and would disable a man in about 7 minutes or less, and " cause death in about 12 minutes. This shows in the clearest way the fearful risk caused by the presence " of afterdamp where the miner trusts only to the indications afforded by his lamp continuing to burn. " Even if the afterdamp were diluted to a hundredth with air, it would still be capable of causing, within " an hour or two, evident symptoms of poisoning.

" Immediately after Experiment No. 107 the intake end of the gallery was blocked with a rough " door, so that the diluted afterdamp was confined within the gallery for the purpose of observing its " properties. Owing to the direction of the wind the afterdamp slowly drifted towards the intake end, and " could be thus conveniently observed at the door. It resembled thick and very ' dirty ' smoke ; and " when well diluted with air, it smelt very distinctly of sulphuretted hydrogen (rotten eggs), just as does " the black smoke emitted by a locomotive. With less dilution, however, this smell could not be detected, " but the afterdamp had an irritant effect on the eyes and throat, this effect being probably due mainly to " the sulphuretted hydrogen.

" A safety lamp burned dimly in the smoky air, and on lowering the flame a distinct cap was seen on " it. A mouse exposed to the air became unconscious, and almost ceased breathing within about a " minute. As this showed that the air was intensely poisonous and probably contained more than 1 per " cent. of carbon monoxide, no one (except men wearing rescue apparatus) was allowed to go out of sight " into the gallery, or to remain in it more than two or three minutes. Several men wearing the Weg " rescue apparatus walked right through the gallery, however. It was afterwards found that silver coins " in their pockets were rendered brown by sulphuretted hydrogen."

* The percentages of hydrogen and methane are included in this calculation as forming part of the crude undiluted " *afterdamp*."

# SUMMARY.

## SUMMARY.


The Committee believe that a concise statement of the main facts contained in this Report may be of value to those who have read this Report. They have, therefore, prepared the following short summary.

At the same time they consider that it may be useful to outline the scope of the work that still remains—the questions which have arisen as a natural outcome of the work that has already been done and the various points in connection with the enquiry, the elucidation of which has been postponed until more urgent matters should be settled.

The main objects of this enquiry are (1) to demonstrate as conclusively as possible the danger that exists from the presence of fine coal dust in the roadways of mines; (2) to discover, if possible, an effective remedy as an alternative to watering; and (3) to investigate the chemical and physical phenomena that accompany coal dust explosions.

The experimental gallery that has been constructed for carrying out the work and the method of experiment that has been employed have been designed to resemble, as far as possible, the conditions of a main intake and haulage road.

The gallery consists of an "intake" and "return." The intake is 7 ft. 6 in. in diameter with a concreted roadway, along which runs a line of rails. The return is 6 ft. in diameter and is zig-zag in form, with relief valves at each bend.

During an experiment a ventilating current of about 50,000 cubic feet per minute has been maintained along the roadway. The coal dust used has in general been pulverised Altofts Silkstone nuts, the quantity employed being 1 lb. per linear foot of roadway, or 0·4 oz. per cubic foot of air space. Ignition has usually been effected by the firing of a charge of 24 oz. of blasting powder from an iron cannon of 2 in. bore, a stemming of 8 in. of dry clay properly rammed being employed.

The fact that coal dust, in the complete absence of firedamp, is explosive when raised as a cloud in air and ignited, has, in the opinion of all who have witnessed the experiments, been definitely established. The information which the Royal Commission on Accidents in Mines desired the members of the Mining Association to furnish has thus been obtained, and the controversy which has existed for more than a quarter of a century has been finally set at rest.

Demonstrations have been given to more than 800 coal owners, colliery officials, inspectors of mines, and scientists from all parts of the United Kingdom, from India and South Africa, and from France, Germany and America. The similarity to mining conditions which has been maintained throughout the demonstrations has enabled those who have witnessed them to realise how an explosion of coal dust can account for the destruction which has been observed after mine disasters; such destruction being, until recent years, generally attributed to explosions of firedamp. It is certain that the demonstrations convey an impression of the danger in a more vivid manner than can be given by mere verbal warnings or by the writing of scientific papers on the subject. Many people, therefore, have expressed the opinion

that the demonstrations form as valuable a part of the work as any that has been done. For the realisation of a danger is in itself a safeguard against that danger.

In the course of the demonstrations (which occupied practically the whole of the summer and autumn of 1908), many interesting facts have been recorded, and a close comparison has been established with the effects observed during the recovery of a mine after an explosion.

In particular it has been noticed that the position of "broad and narrow bands" of coal dust on pit props in the gallery apparently bears no relation to the point of origin of the explosion.

Crusts of coke, on the other hand, have usually been found on the side of the prop facing the direction of the explosion.

The significance of these observations will be readily appreciated by those who have had the experience of recovering a mine after an explosion.

The development of the flame of the explosion after it issues from the downcast end of the gallery has been studied by means of cinematograph ("Kinora") records. The existence of a "pioneering cloud" in front of the explosion has been established, and evidence has been obtained that the true flame of the explosion has a length of from 60 to 80 feet, or possibly less. Lengths of flame outside the gallery of 150 ft. and upwards that have been recorded are shown to be due to the subsequent burning of the cloud of coal dust that issues in advance of the flame.

Concurrently with experiments, to achieve the second object of the enquiry, the obtaining of a remedy, the Committee decided that laboratory investigations should be conducted. They considered that any remedial measure would rest upon a surer foundation if the practical tests were amplified by scientific investigations. At the same time they were aware of many points in connection with the enquiry which still formed the subject of controversy amongst mining engineers, and which were essentially laboratory researches.

A laboratory has, therefore, been built and equipped specially for the purpose at the Experimental Station. The investigations were begun during the winter of 1908. As a preliminary measure, it was found necessary to experiment with methods of analysis, since no standard methods for coal analysis have been decided upon in England. It is hoped that the methods described may be used as standards by other workers so as to ensure uniformity and enable comparison to be made between their results.

In order to study the phenomena occurring during the explosions systematically, accurate data were required concerning (1) the pressure developed, (2) the velocity with which the pressure is propagated, (3) the products of combustion, and (4) the temperature attained during explosive combustion.

Special instruments have been designed for recording all these data and have been made by the Cambridge Scientific Instrument Company. A detailed description of the manner of working these instruments is given in order that it may be seen with what accuracy records can be made.

As regards the finding of a remedy for coal dust explosions as an alternative to watering, a study of the experiments that have been made with stone dust will show that the efforts of the Committee in this direction seem to have been attended with a large measure of success.

It would appear that the presence of a cloud of incombustible dust in the path of a coal dust explosion that has travelled 275 ft. checks the continued propagation of the explosion.

The experiments in which stone dust has been intimately mixed with coal dust also tend to show that as the percentage of incombustible dust is increased it becomes increasingly difficult either to originate an explosion in the mixture or to cause an explosion to be propagated.

It is further shown that the use of stone dust might strike effectually at the root of the danger by controlling one of the factors that are essential for the occurrence of a coal dust explosion—namely, the inflammability of the dust.

The earliest experiments with stone dust having given unmistakable indications of its possible value, the management of the Altofts Collieries were asked to make trials of its application in the mine, with a view to ascertaining the cost and labour required.

The first scheme adopted by them was to isolate various parts of the mine by means of "zones" of stone dust, the dust being either scattered along the sides of the roadway or placed upon specially-made shelves. Further consideration, however, led to the abandonment of zones and the institution of the principle of scattering stone dust wherever there was coal dust.

It has been found that the cost of treatment in the latter manner at Altofts Collieries works out at about one-eighth of a penny per ton of coal raised.

The question of the mode of propagation of coal dust explosions is complicated by the lack of exact knowledge that exists regarding coal itself. The laboratory investigations that have been begun with a view to obtaining the information required concerning coal involve an examination of (1) the volatile constituents of coal, (2) the results of distillation of coal at different temperatures, (3) the composition of the gases evolved on first heating, and (4) the effect of momentary heating on coal dust.

So far as these investigations have progressed they indicate that it is possible by a laboratory test alone to determine the relative degree of danger to be apprehended from the dust from any particular coal. Such a prediction should be possible after correlating the results obtained from a certain number of coals on explosion in the gallery with their behaviour under different modes of heat treatment in the laboratory.

In addition to this work on the heat treatment of coal, laboratory investigations are also proceeding respecting the action of oxygen (air) upon incandescent carbon, the explosion of firedamp and air under special conditions, the influence of weathering on the inflammability of coal dust, and the effect of the presence of incombustible dust on gaseous explosions.

Another method of investigation, which may ultimately throw some light upon the mode of propagation of coal dust explosions, has also been undertaken : namely, the examination, by means of the microscope, of the material left after an explosion.

Fortunately for the purposes of this enquiry, dust collected from the underground roadways after the Altofts Explosion of 1886 was submitted to microscopical examination at that time, and evidence regarding it given before the Royal Commission on Coal Dust in Mines in 1891. These selections have been preserved so that it has been possible to compare the dust collected after the

explosions in the gallery with that remaining after an actual colliery disaster, the coal in both cases being from the same seam.

The samples of dust show, in general, the same characteristics : the different products of decomposition of coal by heat—tar, pitch, coke, particles of ash and smoke—and such substances as fossil wood, microspores and macrospores are all represented in both the mine dust and the "gallery" dust. There is always present a large quantity of unaltered coal dust.

In addition, the presence of two types of bodies of characteristic appearance have been discovered, to which the names of "carbospheres" and "microspheres" have been given. These bodies are always found in considerable quantity among the dust left after an explosion in the gallery, and they have also been recognised among the mine dust. It is believed that they will be found to have played an important part in the development of the explosion.

Before describing the experiments that have been made in the gallery to study the mode of propagation of coal dust explosions, the Committee have considered it advisable to give a brief outline of the previous work that has been done regarding gaseous explosions ; for there is considerable similarity between the phenomena exhibited by the explosive combustion of a mixture of an inflammable gas and of a finely divided solid and air. A comparison is also drawn between the two.

The problem of the mode of propagation of coal dust explosions is a very complicated one. This Report must consist, as far as this part of the enquiry is concerned, largely of an outline of the preparations that have been made for studying the problem systematically, such preparations having necessarily occupied the major portion of the time that has elapsed since the work was decided upon. The results of the preliminary experiments made so far have given an insight into the manner of propagation during the initial stages of the explosion ; but it is essential that the phenomena occurring after a much greater distance of travel should be studied before any definite statement can be made regarding the maximum destructive effect possible.

Of the facts that have been established the most important are the increase in the pressure developed with increased distance of travel of the explosion, the marked influence of the presence of obstructions in causing the explosion to be propagated with greater violence and the possibility of propagating an explosion through a cloud of wood-charcoal dust and air.

There are many points of great interest that have been observed, but they require confirmation before any definite statement can be made regarding them.

In addition to the work that has already been mentioned in the body of the Report as not yet completed, it will readily be understood that there are many points which still require elucidation.

It is, in particular, desirable that experiments should be made with air currents of varying degrees of saturation of moisture. For there is reason to believe that, up to a certain point, the presence of moisture in the air of a mine is favourable to the propagation of explosion, and is therefore dangerous.

It is also of importance that experiments should be made, on a large scale, with air currents containing a small percentage of firedamp, such as is generally present in the ventilating current of most mines. This is necessary in order to determine whether any remedies which may suggest themselves can overcome the additional violence that the presence of a small percentage of gas will cause.

Of the many other questions, perhaps the most important are :—

(*a*) The determination of the maximum and of the minimum quantity of coal dust that will allow explosion to be propagated ; either in pure air or in air containing a small percentage of firedamp.

(*b*) The testing of permitted explosives under various conditions.

(*c*) The determination of the minimum volume, intensity, and duration of flame necessary to cause ignition of coal dust when raised as a cloud in air.

The Committee hope that they will be placed in a position that will enable them to investigate these and other matters, and thus bring the work to a satisfactory conclusion.

The experimental work has been carried out by the following :—

W. E. Garforth, Executive Member of Committee.
Assistants, W. D. Lloyd and G. F. Eagar.

R. V. Wheeler, physical and chemical investigations.
Assistants, T. F. E. Rhead and M. J. Burgess.

H. Crowther, microscopical investigations.

W. H. Galletly, engineer, and in charge of records.
Assistant, A. C. Morton.

W. Clegg, superintendent of plant and accessories.
Assistant, R. Clegg.

J. Hopwood, electrical engineering work.
Assistant, C. Haslop.

J. W. Hollis and C. Abson, clerical.

The photographs of the explosions are by H. Crowther and W. H. Galletly ; those of the instruments and the chemical apparatus by the Cambridge Scientific Instrument Company Limited and C. W. Cook and Co. respectively.

The Committee desire to express their thanks to the Council of the Leeds Philosophical and Literary Society for their kindness in permitting Mr. Crowther to assist in the experiments.

The Committee also wish to thank Messrs. Pope and Pearson Limited for the valuable facilities they have afforded towards the carrying out of the investigation.

(Signed) LINDSAY WOOD,
W. E. GARFORTH,
C. PILKINGTON,
J. T. FORGIE,
W. W. HOOD.

London,
*8th November, 1910.*

## APPENDIX I.

# EXPERIMENTS WITH WELSH, SCOTCH AND SOUTH AFRICAN COALS.

# APPENDIX I.

## EXPERIMENTS WITH WELSH, SCOTCH, AND SOUTH AFRICAN COALS.

The experiments recorded in the main body of this Report have all been made with dust from Silkstone coal for the sake of uniformity. Several other samples of coal have, however, been tested on special occasions. Records of the trials made, both in the Explosion Gallery and in the Laboratory, are given in this Appendix in the same form in which they were sent to those specially interested.

### WELSH COAL DUSTS.

Anthracite. Paris nuts from Pontyberem Colliery. Lab. No., B.

Proximate analysis :—

| | |
|---|---|
| Volatile matter | 8·0 per cent. of ash-free, dry coal |
| Fixed carbon | 92·0 |

The coal as received contained 1·4 per cent. moisture and 3·9 per cent. ash.

Ultimate analysis :—

| | |
|---|---|
| Carbon | 92·66 per cent. of ash-free, dry coal |
| Hydrogen | 3·14 |
| Oxygen | 2·20 |
| Nitrogen | 0·99 |
| Sulphur | 1·01 |

Calorific value, 14,320 B.T.U. as received; 15,120 B.T.U. ash-free, dry coal.

Distillation at 900 degs. Cent. (Retort temperature.) (*See* page 62.)

Gas evolved :—

| | | |
|---|---|---|
| During 1st minute | 120 c.c. | |
| ,, 2nd ,, | 95 | |
| ,, 3rd ,, | 40 | |
| ,, 4th ,, | 30 | |
| ,, 5th ,, | 15 | |
| | —— | 300 c.c. in 1st five minutes |
| ,, next 5 minutes | 40 | |
| ,, ,, 5 ,, | 10 | |
| ,, ,, 15 ,, | 20 | |
| ,, ,, 30 ,, | 5 | |

| | |
|---|---|
| Total length of heating | 60 minutes |
| Total gas evolved | 193 c.c. per gramme of ash-free, dry coal |
| Total volatile matter | 7·82 per cent. |
| Tarry matter | 0·80 |

Analysis of gas evolved :—

| | |
|---|---|
| Benzene | 1·35 per cent. nitrogen-free gas |
| Carbon dioxide | 1·55 |
| Ethylene | 0·25 |
| Carbon monoxide | 9·35 |
| Hydrogen | 70·50 |
| Methane | 15·95 |
| Ethane | 1·05 |

### EXPERIMENTS Nos. 40 and 40A.—November 9th, 1908.

Two attempts to obtain an explosion were made, in each case with a coal dust zone of 260 ft. in front of the point of ignition. In neither case did the flame travel any distance towards the downcast, *i.e.*, against the normal direction of the air current, but towards the return the flame was propagated a distance of 280 ft. in Experiment No. 40, and 285 ft. in Experiment No. 40A.

The dust obtained by pulverising the nut coal was very coarse compared with that obtained from Silkstone bituminous coal, and it is most probable that in this lies the reason for the failure to propagate flame towards the downcast, an insufficient quantity of the very fine dust necessary being present.

The degree of fineness was :—

| | |
|---|---|
| Remaining on 100 mesh | 19·5 per cent. |
| Through 100 on 150 | 16·0 |
| „ 150 on 200 | 7·0 |
| „ 200 on 240 | 23·0 |
| „ 240 and finer | 34·5 |

Further experiments with dust from anthracite coal are necessary.

## WELSH BITUMINOUS COAL.

Bituminous. Three-quarter Seam, Abertillery. Lab. No., C.

Proximate analysis ;—

| | |
|---|---|
| Volatile matter | 30·10 per cent. of ash-free, dry coal |
| Fixed carbon | 69·90 |

The coal as received contained 0·96 per cent. moisture, and 7·65 per cent. ash.

Ultimate analysis :—

| | |
|---|---|
| Carbon | 85·72 per cent. of ash-free, dry coal |
| Hydrogen | 4·93 |
| Oxygen | 7·34 |
| Nitrogen | 1·09 |
| Sulphur | 0·92 |

Calorific value, 13,980 B.T.U. per lb. as received ; 15,300 B.T.U. per lb. ash-free, dry coal.

Distillation at 900 degs. Cent. (Retort temperature.)

Gas evolved :—

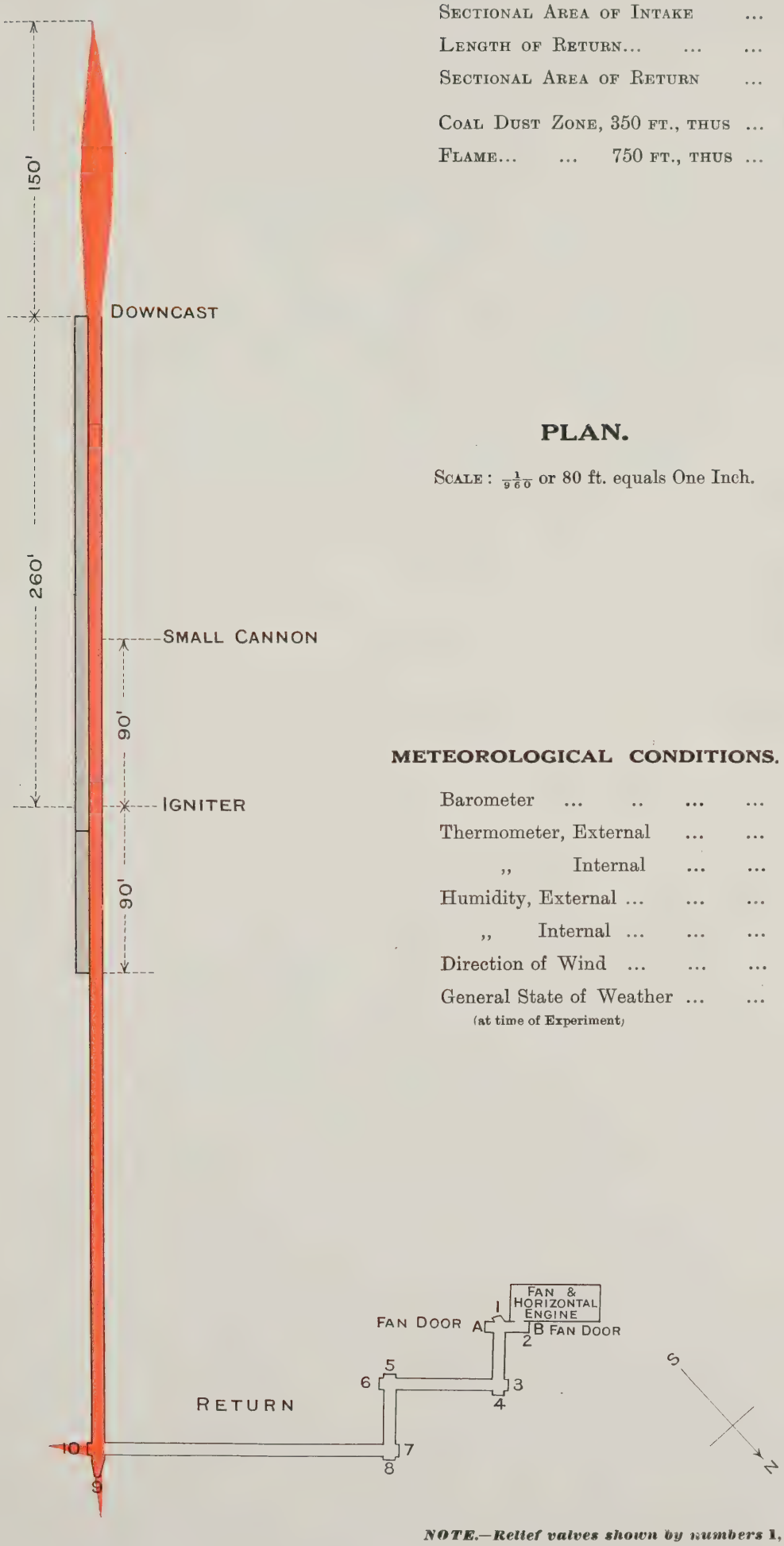
| | | |
|---|---|---|
| During 1st minute | 200 c.c. | |
| „ 2nd „ | 105 | |
| „ 3rd „ | 50 | |
| „ 4th „ | 15 | |
| „ 5th „ | 10 | |
| | —— | 380 c.c. in 1st 5 minutes |
| „ next 5 minutes | 50 | |
| „ „ 5 „ | 20 | |
| „ „ 15 „ | 25 | |
| „ „ 15 „ | 5 | |
| „ „ 30 „ | 20 | |
| Total length of heating | 75 minutes | |
| Total gas evolved | 270 c.c. per gramme ash-free, dry coal | |
| Total volatile matter | 30·12 per cent. | |
| Tarry matter | 9·66 | |

Analysis of gas evolved :—

| | |
|---|---|
| Benzene | 1·85 per cent. nitrogen-free gas |
| Carbon dioxide | 1·65 |
| Acetylene | 0·05 |
| Ethylene | 1·05 |
| Carbon monoxide | 11·25 |
| Hydrogen | 57·05 |
| Methane | 21·80 |
| Ethane | 5·25 |

# EXPERIMENT No. 37. NOVEMBER 5TH, 1908.

| | |
|---|---|
| LENGTH OF INTAKE ... ... ... | 600 ft. |
| SECTIONAL AREA OF INTAKE ... | 41 sq. ft. |
| LENGTH OF RETURN... ... ... | 295 ft. |
| SECTIONAL AREA OF RETURN ... | 28 sq. ft. |
| COAL DUST ZONE, 350 FT., THUS ... | |
| FLAME... ... 750 FT., THUS ... | |




## PLAN.

SCALE: $\frac{1}{960}$ or 80 ft. equals One Inch.

## METEOROLOGICAL CONDITIONS.

| | |
|---|---|
| Barometer ... .. ... ... | 30·18 in. |
| Thermometer, External ... ... | 51° Fahr. |
| ,, Internal ... ... | 57° ,, |
| Humidity, External ... ... ... | 86 % |
| ,, Internal ... ... ... | 81 % |
| Direction of Wind ... ... ... | North-East. |
| General State of Weather ... ... (at time of Experiment) | Fine, 1·5 p.m. |

***NOTE.—Relief valves shown by numbers 1, 2, 3, etc.***

## EXPERIMENT No. 37.

### Main Object of Experiment.

Trial of South Wales bituminous coal.

### Special Conditions.

Owing to the belief that this dust would produce more violent effects than the Silkstone dust, a length of 260 ft. only was placed in front of the point of ignition, instead of the "standard" length of 275 ft.

Position of igniter, 260 ft. from downcast.

Quantity of air, 55,000 ft. per minute.

Velocity of air, 1,340 ft. per minute.

Quantity of dust, 1 lb. per linear foot = 0·39 oz. per cubic foot.

Large cannon, charge 24 oz.; clay stemming, 8 in.

Small cannon, charge 4 oz.; clay stemming, 3 in.

Number of sets of timber in main intake 66, placed 9 ft. apart throughout the intake.

### Name and Particulars of Coal Used.

Seam, Three-quarter.

Colliery, Powell Tillery, Abertillery, Monmouthshire.

Analysis.

| | Per cent. | |
|---|---|---|
| Moisture | 0·96 | |
| Volatile matter | 27·75 | of dry coal |
| Fixed carbon | 64·60 | „ „ |
| Ash | 7·65 | „ „ |

Fineness.

| | Per cent. |
|---|---|
| Remaining on 100 mesh | 3·54 |
| Through 100 on 150 „ | 7·62 |
| „ 150 on 200 „ | 0·87 |
| „ 200 on 240 „ | 6·04 |
| „ 240 and finer | 81·93 |

### Result.

A most violent explosion.

Flame shot out from downcast end 150 ft., and also issued from valves 9 and 10, which were completely wrecked.

Tub blown out and wrecked, wheels found 457 ft. away.

Twelve props were blown out through valve No. 9, as well as many out of the downcast end.

Fig. 88.—Flame from explosion of South Wales Bituminous Coal issuing from Downcast End.

Fig. 89.—Valve No. 9 blown out by the explosion.

## WELSH STEAM COAL.

Steam coal (semi-bituminous). Penrhiwceiber Navigation Collieries. Lab. No., D.

Proximate analysis :—

| | |
|---|---|
| Volatile matter | 16·05 per cent. of ash-free, dry coal |
| Fixed carbon | 83·95 |

The coal as received contained 0·70 per cent. of moisture and 3·5 per cent. of ash.

Ultimate analysis :—

| | |
|---|---|
| Carbon | 90·72 per cent. of ash-free, dry coal |
| Hydrogen | 4·23 |
| Oxygen | 2·99 |
| Nitrogen | 1·25 |
| Sulphur | 0·81 |

Calorific value, 14,890 B.T.U. per lb. as received ; 15,550 B.T.U. per lb. ash-free, dry coal.

Distillation at 900 degs. Cent. (Retort temperature.)

Gas evolved :—

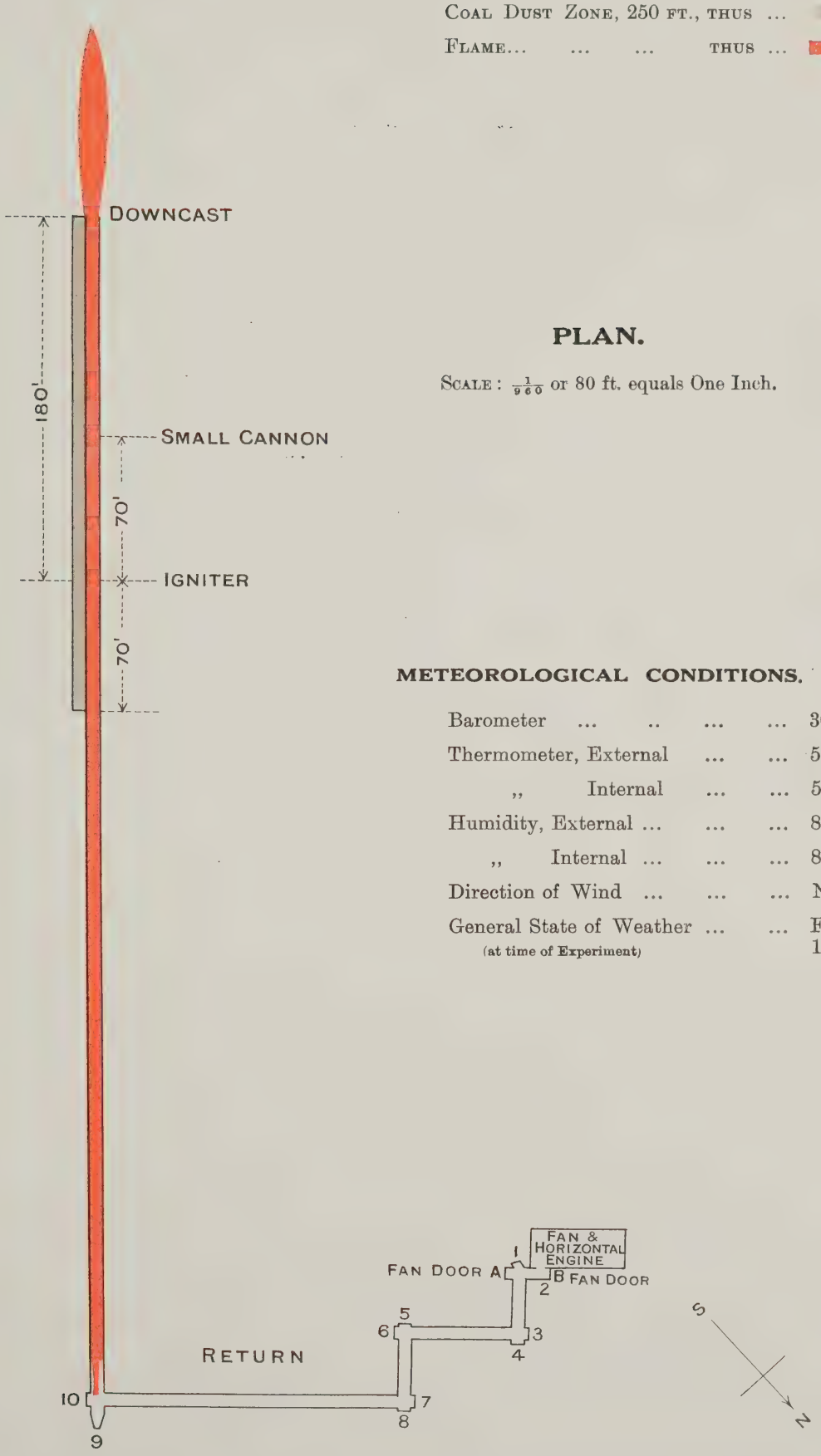
| | | |
|---|---|---|
| During 1st minute | 160 | |
| „ 2nd „ | 115 | |
| „ 3rd „ | 65 | |
| „ 4th „ | 35 | |
| „ 5th „ | 20 | |
| | —— | 395 c.c. in 1st 5 minutes |
| „ next 5 minutes | 45 | |
| „ „ 5 „ | 20 | |
| „ „ 15 „ | 15 | |
| „ „ 15 „ | 5 | |
| „ „ 30 „ | 5 | |
| Total length of heating | 75 minutes | |
| Total gas evolved | 235 c.c. per gramme of ash-free, dry coal | |
| Total volatile matter | 15·80 per cent. | |
| Tarry matter | 2·95 | |

Analysis of gas evolved :—

| | |
|---|---|
| Benzene | 0·90 per cent. nitrogen-free gas |
| Carbon dioxide | 1·05 |
| Ethylene | 0·69 |
| Carbon monoxide | 5·71 |
| Hydrogen | 64·40 |
| Methane | 26·10 |
| Ethane | 1·17 |

# EXPERIMENT No. 38. NOVEMBER 6TH, 1908.

| | |
|---|---|
| LENGTH OF INTAKE ... ... ... | 600 ft. |
| SECTIONAL AREA OF INTAKE ... | 41 sq. ft. |
| LENGTH OF RETURN... ... ... | 295 ft. |
| SECTIONAL AREA OF RETURN ... | 28 sq. ft. |
| COAL DUST ZONE, 250 FT., THUS ... | |
| FLAME... ... ... THUS ... | |




## PLAN.

SCALE: $\frac{1}{960}$ or 80 ft. equals One Inch.

## METEOROLOGICAL CONDITIONS.

| | |
|---|---|
| Barometer ... .. ... ... | 30·12 in. |
| Thermometer, External ... ... | 51° Fahr. |
| ,, Internal ... ... | 55° ,, |
| Humidity, External ... ... ... | 86 % |
| ,, Internal ... ... ... | 81 % |
| Direction of Wind ... ... ... | North-West. |
| General State of Weather (at time of Experiment) ... ... | Fine, 1·5 p.m. |

***NOTE.—Relief valves shown by numbers 1, 2, 3, etc.***

## EXPERIMENT No. 38.

### Main Object of Experiment.

Trial of Welsh steam coal.

### Special Conditions.

This dust was reputed to be of a very inflammable nature. A zone of 180 ft. only was therefore placed in front of the point of ignition instead of the "standard" length 275 ft.

Position of igniter, 180 ft. from downcast.

Quantity of air, 54,000 cubic feet per minute.

Velocity of air, 1,320 ft. per minute.

Quantity of dust, 1 lb. per linear foot = 0·39 oz. per cubic foot.

Large cannon, charge 24 oz.; clay stemming, 8 in.

Small cannon, charge 4 oz.; clay stemming, 3 in.

Number of sets of timber in main intake, 55, placed every 9 ft. beginning 100 ft. from the return.

### Name and Particulars of Coal Used.

Seam,

Colliery, Penrhiwceiber Navigation Collieries.

Analysis.

| | Per cent. |
|---|---|
| Moisture | 0·70 |
| Volatile matter | 15·0 of dry coal |
| Fixed carbon | 76·4 ,, ,, |
| Ash | 8·6 ,, ,, |

Fineness.

| | Per cent. |
|---|---|
| Remaining on 100 mesh | 1·30 |
| Through 100 on 150 ,, | 3·24 |
| ,, 150 on 200 ,, | 0·82 |
| ,, 200 on 240 ,, | 3·15 |
| ,, 240 and finer | 91·49 |

### Result.

A flame of a dull red colour shot out from downcast.

The tub was blown out only 25 ft.

Nine sets of timber near the point of ignition blown down, the remainder were left standing.

Fig. 90.—Flame from explosion of South Wales Steam Coal issuing from Downcast End.

## SCOTCH COAL.

Bituminous. Dysart Main Seam, Lochhead Colliery. Lab. No., E.

Proximate analysis:—

| | |
|---|---|
| Volatile matter | 40·6 per cent. of ash-free, dry coal |
| Fixed carbon | 59·4 |

The coal as received contained 12·35 per cent. moisture and 4·2 per cent. of ash.

Ultimate analysis:—

| | |
|---|---|
| Carbon | 78·18 per cent. of ash-free, dry coal |
| Hydrogen | 5·18 |
| Oxygen | 14·62 |
| Nitrogen | 0·81 |
| Sulphur | 1·21 |

Calorific value, 11,340 B.T.U. per lb. as received; 13,590 B.T.U. per lb. ash-free, dry coal.

Distillation at 900 degs. Cent. (Retort temperature.)

Gas evolved:—

| | | |
|---|---|---|
| During 1st minute | | Gas was evolved very rapidly, about 400 c.c. being collected during the first two minutes |
| „ 2nd „ | | |
| „ 3rd „ | | |
| „ 4th „ | | |
| „ 5th „ | | |
| | —— | 480 c.c. in 1st 5 minutes |
| „ next 5 minutes | 45 | |
| „ „ 5 „ | 25 | |
| „ „ 15 „ | 20 | |
| „ „ 15 „ | 10 | |
| „ „ 30 „ | 10 | |
| Total length of heating | 75 minutes | |
| Total gas evolved | 283 c.c. per gramme ash-free, dry coal | |
| Total volatile matter | 41·96 per cent. | |
| Tarry matter | 11·2 | |

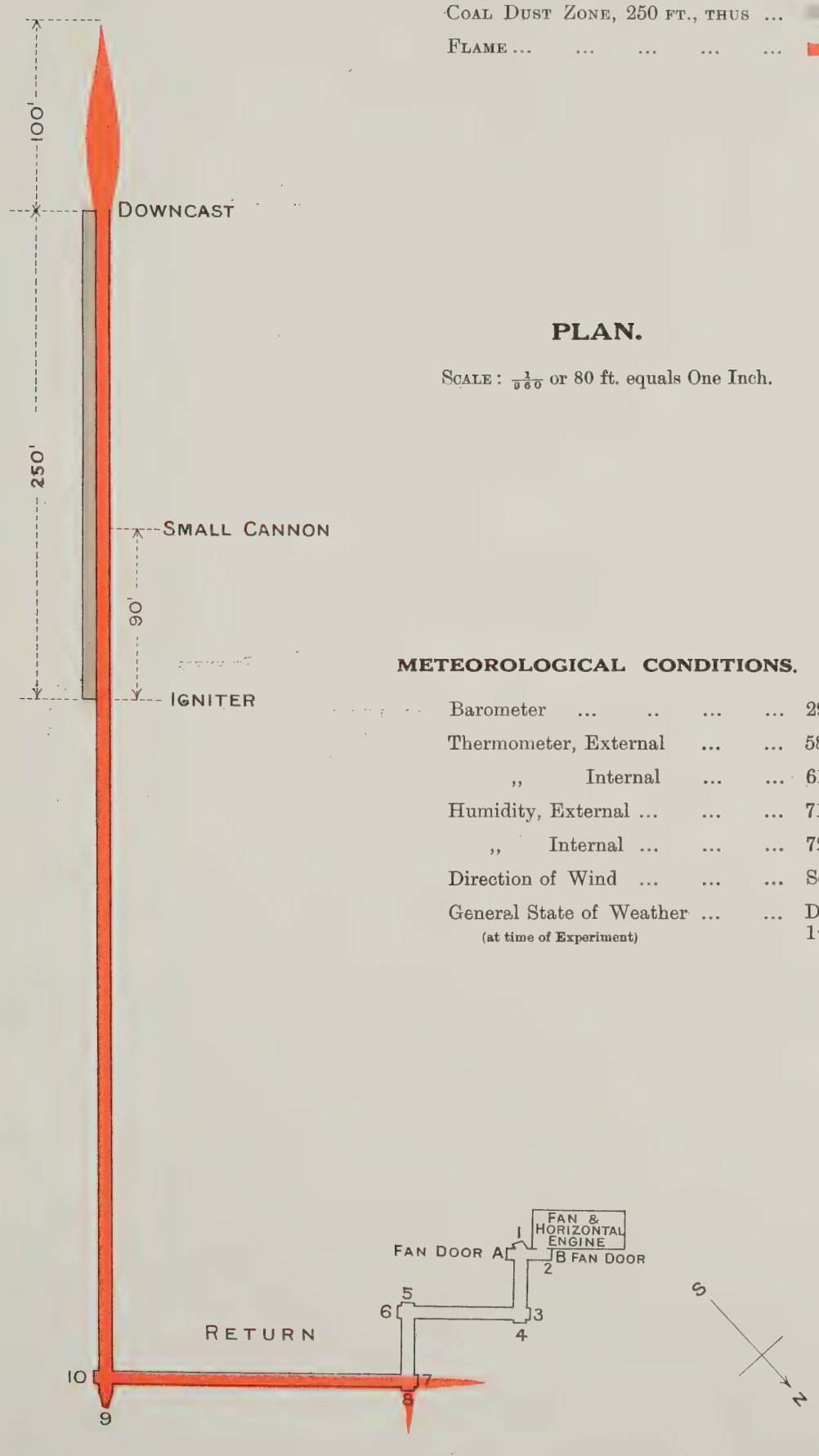
Analysis of gas evolved:—

| | |
|---|---|
| Benzene | 2·99 per cent. nitrogen-free gas |
| Carbon dioxide | 3·48 |
| Ethylene | 1·86 |
| Carbon monoxide | 22·21 |
| Hydrogen | 48·58 |
| Methane | 15·68 |
| Ethane | 5·22 |

# EXPERIMENT No. 56.

JULY 6TH, 1909.

| | |
|---|---|
| LENGTH OF INTAKE ... ... ... | 600 ft. |
| SECTIONAL AREA OF INTAKE ... | 41 sq. ft. |
| LENGTH OF RETURN... ... ... | 295 ft. |
| SECTIONAL AREA OF RETURN ... | 28 sq. ft. |
| COAL DUST ZONE, 250 FT., THUS ... | |
| FLAME ... ... ... ... ... | |




## PLAN.

SCALE : $\frac{1}{960}$ or 80 ft. equals One Inch.

## METEOROLOGICAL CONDITIONS.

| | |
|---|---|
| Barometer ... .. ... ... | 29·55 in. |
| Thermometer, External ... ... | 58° Fahr. |
| ,, Internal ... ... | 61° ,, |
| Humidity, External ... ... ... | 71 % |
| ,, Internal ... ... ... | 72 % |
| Direction of Wind ... ... ... | South-West. |
| General State of Weather ... ... (at time of Experiment) | Dull, 1·0 p.m. |

*NOTE.—Relief valves shown by numbers 1, 2, 3, etc.*

## EXPERIMENT No. 56.

### Main Object of Experiment.

Trial of Scotch bituminous coal.

### Special Conditions.

A zone of 250 ft. placed in front of point of ignition; no dust placed behind.

Position of igniter, 250 ft. from downcast.

Quantity of air, 50,000 cubic feet per minute.

Velocity of air, 1,220 ft. per minute.

Quantity of dust, 1 lb. per linear foot = 0·39 oz. per cubic foot.

Large cannon, charge 24 oz.; clay stemming, 8 in.

Small cannon, charge 4 oz.; clay stemming, 3 in.

Number of sets of timber in main intake, 39, placed every 9 ft. from the downcast.

### Name and Particulars of Coal Used.

Seam, Dysart Main, pulverised nut coal.

Colliery, Lochhead Colliery, East Wemyss.

Analysis.

| | Per cent. | |
|---|---|---|
| Moisture | 12·35 | |
| Volatile matter | 39·60 | of dry coal |
| Fixed carbon | 55·70 | „ „ |
| Ash | 4·60 | „ „ |

Fineness.

| | Per cent. |
|---|---|
| Remaining on 100 mesh | 16·0 |
| Through 100 on 150 „ | 19·0 |
| „ 150 on 200 „ | 4·5 |
| „ 200 on 240 „ | 11·5 |
| „ 240 and finer | 49·0 |

### Result.

Flame shot out about 100 ft. from downcast end, and also appeared at valve No. 7.

Tub blown out 130 ft.

The explosion was not so violent as with Silkstone dust (note the degree of fineness of the dust), the maximum pressure recorded being only 15·40 lb. per square inch (manometer record).

Fig. 91.—Flame from explosion of Scotch Bituminous Coal. Near view.

Fig. 92.—General view of explosion.

## SOUTH AFRICAN COALS.

Three samples of nut coal, from Durban, Elandslaagte, and St. George collieries respectively, were received during September 1909, and tested on the 28th, 29th, and 30th of that month.

### I.

*Durban coal.* Lab. No., H.

Proximate analysis :—

| | |
|---|---|
| Volatile matter | 26·6 per cent. of ash-free, dry coal |
| Fixed carbon | 73·4 |

The coal as received contained 1·05 per cent. moisture and 13·80 per cent. ash.

Ultimate analysis :-

| | |
|---|---|
| Carbon | 86·32 per cent. of ash-free, dry coal |
| Hydrogen | 4·76 |
| Oxygen | 5·17 |
| Nitrogen | 1·76 |
| Sulphur | 1·99 |

Calorific value, 13,190 B.T.U. per lb. as received ; 15,060 B.T.U. per lb. ash-free, dry coal.

Distillation at 900 degs. Cent. (Retort temperature.)

Gas evolved :—

| | | |
|---|---|---|
| During 1st minute | 330 c.c. | |
| ,, 2nd ,, | 90 | |
| ,, 3rd ,, | 20 | |
| ,, 4th ,, | 10 | |
| ,, 5th ,, | 10 | |
| | | 460 c.c. during 1st 5 minutes |
| ,, next 5 minutes | 20 | |
| ,, ,, 5 ,, | 10 | |
| ,, ,, 15 ,, | 20 | |
| ,, ,, 15 ,, | 5 | |
| ,, ,, 30 ,, | 10 | |
| Total length of heating | 75 minutes | |
| Total gas evolved | 295 c.c. per gramme of ash-free, dry coal | |
| Total volatile matter | 28·25 per cent. | |
| Tarry matter | 7·70 | |

Analysis of gas evolved :—

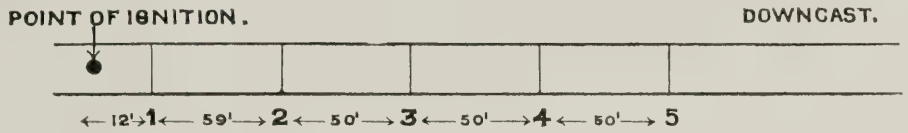
| | |
|---|---|
| Benzene | 2·00 nitrogen-free gas |
| Carbon dioxide | 0·70 |
| Acetylene | 0·10 |
| Ethylene | 2·05 |
| Carbon monoxide | 10·30 |
| Hydrogen | 62·05 |
| Methane | 19·40 |
| Ethane | 3·45 |

### EXPERIMENT No. 102.—September 28th, 1909.

The explosion was not very violent, a maximum pressure of only 4·4 lb. per square inch being obtained. A similar length of 275 ft. of Silkstone dust gives a maximum pressure of 50 lb. per square inch ; it must be remembered, however, that the Durban coal contains nearly 14 per cent. of ash, as against an average of 4 per cent. in Silkstone nuts. It is interesting, therefore, to compare its behaviour with that of a mixture of Silkstone coal dust with 10 per cent. of added stone dust (making about 13 per cent. of "ash"). Such a comparison is given by experiment No. 83 of August 27th, 1909, in which the maximum pressure recorded was 7 lb. per square inch. This strong resemblance on explosion between a coal dust containing 14 per cent. of ash *naturally* and one containing 13 per cent. *artificially* is very striking.

On examining the pressure curves (102 A and B, Plate XXIII.), it will be seen that the rate of travel of pressure is quite slow—the pressure recorded on manometer A lagging nearly $\frac{1}{2}$ second after that recorded on B (100 ft. nearer the point of ignition).

The record of the velocity of propagation of flame was made between 5 points, as indicated in the accompanying diagram:—




The distance between the point of ignition and No. 1 was 12 ft.; the velocity recorded being between

1 and 2 = 59·00 ft. = 113·5 ft. per second.
2 ,, 3 = 50·00 ,, = 85·0 ,, ,,
3 ,, 4 = 50·00 ,, = 118·0 ,, ,,
4 ,, 5 = 50·00 ,, = 554·5 ,, ,,

The rate of travel is thus very uneven, a sudden rush near the end being apparent; this could also be observed from the manner of movement of the flame projected outside the gallery, the flame seeming to be pulled back for a fraction of a section and then to travel forward with greater speed.

Note.—The recording manometers are fixed on the gallery at distances of 225 ft. (A) and 125 ft. (B) from the point of ignition. (*See* Plate XXIII.).

In each experiment the time of ignition has been recorded on each manometer so as to enable comparison to be made of the rate of travel of pressure between one experiment and another. The pressures are plotted as a function of the time from a constant point and are all reduced to the same time basis.

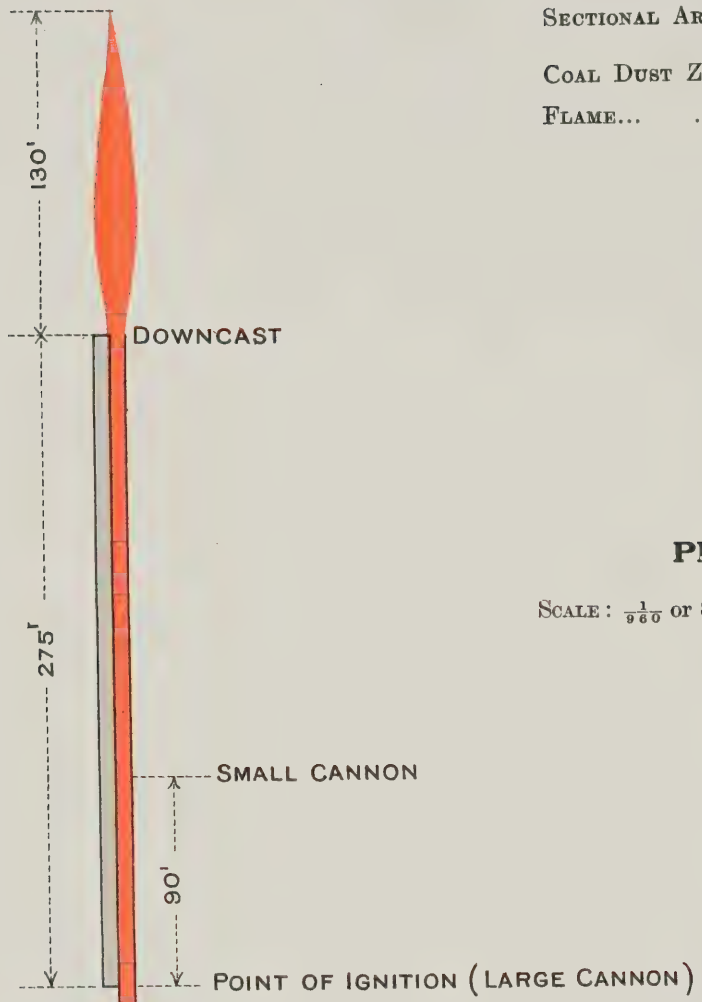
The first part of the curve is due to the pressure produced by the firing of the charge of blasting powder used to ignite the coal dust. To make this clear, the curve produced when the cannon is fired alone, without coal dust present, has been reproduced underneath the explosion curves. This latter record was obtained with the cannon placed 275 ft. from the downcast and charged with 24 oz. of blasting powder.

The vibrations that occur in the first part of the curve are due to the natural period of vibration of the spring of the manometer consequent on the sudden shock caused by the cannon; this natural period has been found to be $\frac{1}{70}$ (70 complete vibrations per second) for the spring employed in these three experiments.

# EXPERIMENT No. 102.

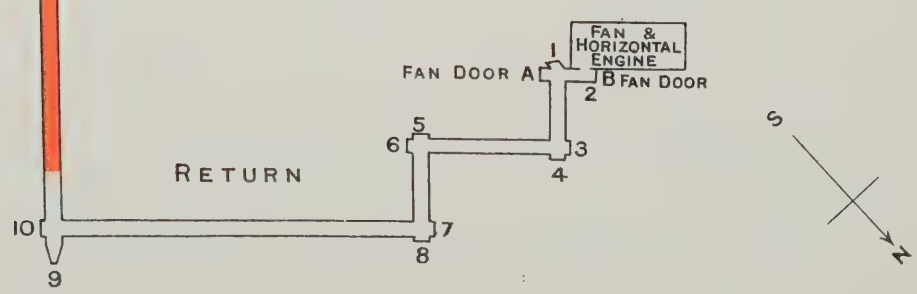
SEPTEMBER 28TH, 1909.

| | |
|---|---|
| LENGTH OF INTAKE ... ... ... | 600 ft. |
| SECTIONAL AREA OF INTAKE ... | 41 sq. ft. |
| LENGTH OF RETURN... ... ... | 295 ft. |
| SECTIONAL AREA OF RETURN ... | 28 sq. ft. |
| COAL DUST ZONE, 275 FT., THUS ... | |
| FLAME... ... 705 FT., THUS ... | |




## PLAN.

SCALE: $\frac{1}{960}$ or 80 ft. equals One Inch.




## METEOROLOGICAL CONDITIONS.

| | |
|---|---|
| Barometer ... .. ... ... | 29·5 in. |
| Thermometer, External Wet, 50° F. | Dry, 51° F. |
| ,, Internal ,, 51° F. | ,, 52° F. |
| Humidity, External ... ... ... | 93 % |
| ,, Internal ... ... ... | 93 % |
| Direction of Wind ... ... ... | South-East. |
| Velocity of Wind ... ... ... | 3 m. per hour. |
| General State of Weather ... ... (at time of Experiment) | Raining, 1·15 p.m. |

***NOTE.—Relief valves shown by numbers 1, 2, 3, etc.***

## EXPERIMENT No. 102.—September 28th, 1909.

### Main Object of Experiment.

Trial of South African coal, Durban.

### Experimental Conditions.

Position of igniter, 275 ft. from downcast.

Quantity of air, 64,000 cubic feet per minute.

Velocity of air, 1,560 ft. per minute.

Quantity of dust, 1 lb. per linear foot = 0·4 oz. per cubic foot.

Large cannon, charge 24 oz.; clay stemming, 8 in.

Small cannon, charge 4 oz.; clay stemming, 4 in.

Number of sets of timber in main intake, 30, fixed every 9 ft. starting from downcast.

### Name and Particulars of Coal Used.

Seam,

Colliery, Durban.

| Analysis. | | Fineness. | |
|---|---|---|---|
| | Per cent. | | Per cent. |
| Moisture | 1·45 | Remaining on 100 mesh | 2·5 |
| | | Through 100 on 150 ,, | 9·5 |
| Volatile matter | 30·50 of dry coal | ,, 150 on 200 ,, | 2·0 |
| Fixed carbon | 58·52 ,, ,, | ,, 200 on 240 ,, | 10·0 |
| Ash | 10·98 ,, ,, | ,, 240 and finer | 76·0 |

### Result.

Flame shot out 130 ft. from downcast. There was a marked back suction, the explosion seeming to stop for a fraction of a second and then gather greater force.

Several sets of timber remained standing.

One strengthening bar of valve No. 10 was broken.

Valve No. 7 badly damaged.

Fig. 93.—Flame from explosion of South African Coal issuing from Downcast End.

II.

*Elandslaagte coal.* Lab. No., G.

Proximate analysis :—

| | |
|---|---|
| Volatile matter | 26·90 per cent. of ash-free, dry coal |
| Fixed carbon | 73·10 |

The coal as received contained 0·91 per cent. moisture and 19·35 per cent. ash.

Ultimate analysis :—

| | |
|---|---|
| Carbon | 84·24 per cent. ash-free, dry coal |
| Hydrogen | 4·83 |
| Oxygen | 6·06 |
| Nitrogen | 2·02 |
| Sulphur | 2·85 |

Calorific value, 12,170 B.T.U. per lb. as received ; 15,260 B.T.U. per lb. ash-free, dry coal.

Distillation at 900 degs. Cent. (Retort temperature.)

Gas evolved--

| | | |
|---|---|---|
| During 1st minute | 325 c.c. | |
| ,, 2nd ,, | 65 | |
| ,, 3rd ,, | 15 | |
| ,, 4th ,, | 15 | |
| ,, 5th ,, | 10 | |
| | —— | 430 c.c. in 1st 5 minutes |
| ,, next 5 minutes | 30 | |
| ,, ,, 5 ,, | 15 | |
| ,, ,, 15 ,, | 20 | |
| ,, ,, 15 ,, | 5 | |
| ,, ,, 30 ,, | 5 | |

| | |
|---|---|
| Total length of heating | 75 minutes |
| Total gas evolved | 314·7 c.c. per gramme of ash-free, dry coal |
| Total volatile matter | 28·39 per cent. |
| Tarry matter | 6·77 |

Analysis of gas evolved :—

| | |
|---|---|
| Benzene | 1·85 per cent. nitrogen-free gas |
| Carbon dioxide | 1·50 |
| Acetylene | 0·35 |
| Ethylene | 0·95 |
| Carbon monoxide | 13·15 |
| Hydrogen | 60·80 |
| Methane | 19·35 |
| Ethane | 2·05 |

EXPERIMENT No. 104.—September 29th, 1909.

Reference to the analysis of this sample of coal will show that it contains nearly 20 per cent. of ash. Previous experiments appeared to show that the addition of stone dust to Silkstone dust was sufficient to prevent the propagation of an explosion when the mixed dusts were laid in the gallery at the rate of 1 lb. per linear foot. It was not surprising, therefore, to find that the Elandslaagte coal, containing as it did nearly 20 per cent. of natural ash, failed to allow explosion to be propagated when the dust was distributed in the same quantity—1 lb. per linear foot. In Experiment No. 103 (September 29th), made in this manner, no flame issued from the downcast end, but examination of cotton wool tell-tales inside the gallery showed that flame had travelled for a certain distance in either direction from the point of ignition, namely, 99 ft. towards the downcast and 265 ft. towards the return. There were no signs of any pressure being developed beyond that due to the cannon-shot.

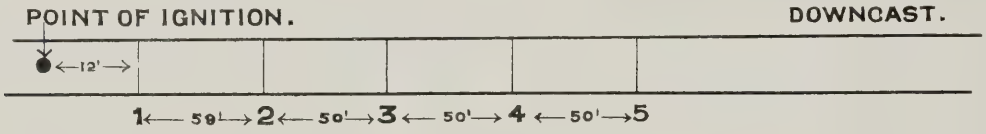
But experiments had shown that when a mixture of 20 per cent. stone dust with Silkstone coal dust is strewn at the rate of *one and a-half* pounds per linear foot, explosion is propagated more or less readily.

An experiment was therefore made with Elandslaagte coal in this quantity.

Flame shot out at the downcast end for 150 ft., and of the sets of timber fixed in the intake only three remained standing.

Reference to the pressure curves (104 A and B) shows that the pressure developed reached a higher maximum than in either of the other two experiments with South African coals, but it must be remembered that the dust was present in quantity half as great again. The true relative inflammability of the coal compared with the two others is given by Experiment No. 103, which, as has already been noted, failed to propagate flame for a greater distance than 99 ft. in front of the point of ignition.

The velocity records showed fluctuations which indicate that the explosion was not propagated very readily ; thus between the points indicated in the accompanying diagram :—

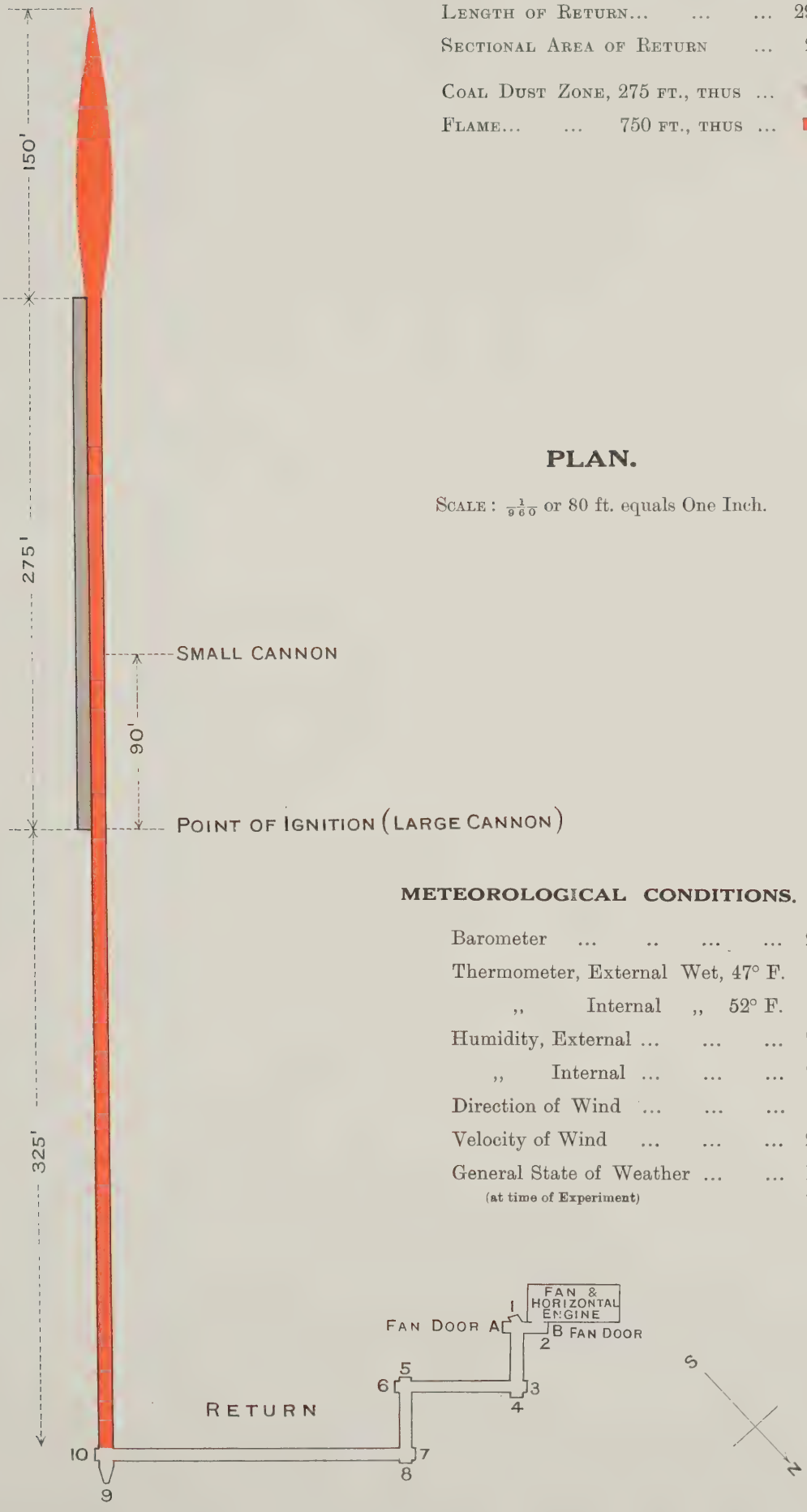



Between No. 1 (12 ft. in front of the point of ignition)
and No. 2 = 59·00 ft. = 138·5 ft. per second
No. 2 „ No. 3 = 50·00 „ = 320·5 „ „
No. 3 „ No. 4 = 50·00 „ = 160·0 „ „
No. 4 „ No. 5 = 50·00 „ = 450·5 „ „

Note.—In making comparison between these experiments, only the phenomena occurring *in front of the point of ignition* should be taken into account ; previous to the firing of the cannon-shot which causes ignition, the ventilating current employed draws an unknown quantity of dust behind the point of ignition, so that the distance to which the flame may travel in this direction is influenced by an unknown factor which may vary from one experiment to another.

# EXPERIMENT No. 104. SEPTEMBER 29TH, 1909.

| | |
|---|---|
| LENGTH OF INTAKE ... ... ... | 600 ft. |
| SECTIONAL AREA OF INTAKE ... | 41 sq. ft. |
| LENGTH OF RETURN... ... ... | 295 ft. |
| SECTIONAL AREA OF RETURN ... | 28 sq. ft. |
| COAL DUST ZONE, 275 FT., THUS ... | |
| FLAME... ... 750 FT., THUS ... | |




## PLAN.

SCALE: $\frac{1}{960}$ or 80 ft. equals One Inch.

## METEOROLOGICAL CONDITIONS.

| | |
|---|---|
| Barometer ... .. ... ... | 29·5 in. |
| Thermometer, External Wet, 47° F. | Dry, 51° F. |
| ,, Internal ,, 52° F. | ,, 56° F. |
| Humidity, External ... ... ... | 75 % |
| ,, Internal ... ... ... | 74 % |
| Direction of Wind ... ... ... | North-East. |
| Velocity of Wind ... ... ... | 2 m. per hour. |
| General State of Weather ... ... (at time of Experiment) | Fair, 4·45 p.m. |

***NOTE.—Relief valves shown by numbers 1, 2, 3, etc.***

## EXPERIMENT No. 104.—September 29th, 1909.

### Main Object of Experiment.

Trial of South African coal. Elandslaagte.

### Special Conditions.

Dust laid at the rate of 1½ lb. per linear foot.

Position of igniter, 275 ft. from downcast.

Quantity of air, 64,000 cubic feet per minute.

Velocity of air, 1,560 ft. per minute.

Quantity of dust, 1½ lb. per linear foot = 0·6 oz. per cubic foot.

Large cannon, charge 24 oz.; clay stemming, 8 in.

Small cannon, charge 4 oz.; clay stemming, 4 in.

Number of sets of timber in main intake, 30, fixed every 9 ft. from the downcast.

### Name and Particulars of Coal Used.

Seam,

Colliery, Elandslaagte.

Analysis.

| | Per cent. |
|---|---|
| Moisture | 0·91 |
| Volatile matter | 21·45 of dry coal |
| Fixed carbon | 59·20 ,, ,, |
| Ash | 19·35 ,, ,, |

Fineness.

| | Per cent. |
|---|---|
| Remaining on 100 mesh | 4·0 |
| Through 100 on 150 ,, | 10·5 |
| ,, 150 on 200 ,, | 1·5 |
| ,, 200 on 240 ,, | 11·0 |
| ,, 240 and finer | 73·0 |

### Result.

Flame of 150 ft. in length projected from downcast end.

Several props remained standing.

Fig. 94.—Flame from explosion of South African Coal.

III.

*St. George.* Lab. No., H.

Proximate analysis :—

| | |
|---|---|
| Volatile matter | 26·6 per cent. ash-free, dry coal |
| Fixed carbon | 73·4 |

This coal as received contained 1·05 per cent. moisture and 13·8 per cent. ash.

Ultimate analysis :—

| | |
|---|---|
| Carbon | 86·32 per cent. |
| Hydrogen | 4·76 |
| Oxygen | 5·17 |
| Nitrogen | 1·76 |
| Sulphur | 1·99 |

Calorific value, 13,010 B.T.U. per lb. as received ; 15,280 B.T.U. per lb. ash-free, dry coal.

Distillation at 900 degs. Cent. (Retort temperature.)

Gas evolved :—

| | | |
|---|---|---|
| During 1st minute | 330 c.c. | |
| „ 2nd „ | 90 | |
| „ 3rd „ | 20 | |
| „ 4th „ | 10 | |
| „ 5th „ | 10 | |
| | | 460 c.c. in 1st 5 minutes |
| „ next 5 minutes | 20 | |
| „ „ 5 „ | 10 | |
| „ „ 15 „ | 20 | |
| „ „ 15 „ | 5 | |
| „ „ 30 „ | 10 | |
| Total length of heating | 75 minutes | |
| Total gas evolved | 295 c.c. per gramme of ash-free, dry coal | |
| Total volatile matter | 28·25 per cent. | |
| Tarry matter | 7·70 | |

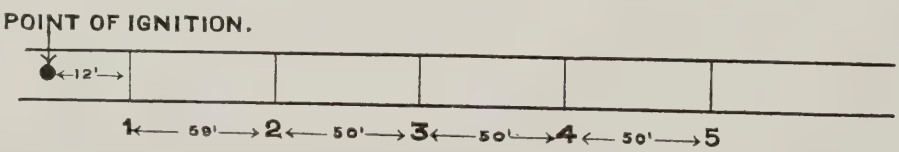
Analysis of gas evolved :—

| | |
|---|---|
| Benzene | 2·00 per cent. nitrogen-free gas |
| Carbon dioxide | 0·70 |
| Acetylene | 0·10 |
| Ethylene | 2·05 |
| Carbon monoxide | 10·30 |
| Hydrogen | 62·05 |
| Methane | 19·40 |
| Ethane | 3·45 |

EXPERIMENT No. 105.—September 30th, 1909.

This dust, containing nearly 14 per cent. of ash, was strewn at the rate of 1 lb. per linear foot in the gallery.

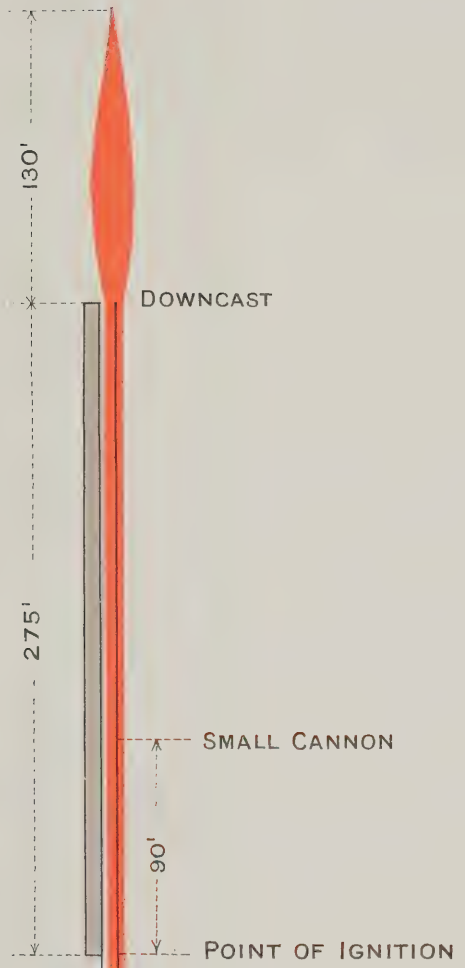
Explosion was propagated, but very slowly ; the flame appeared almost to die out after travelling for about 100 ft., but then went forward again more rapidly. This is well shown in the pressure curves (105 A and B), and appears also in the record of velocity between the following points :—




Between No. 1 (12 ft. from point of ignition)
and No. 2 = 59·00 ft. = 632·0 ft. per second
No. 2 „ No. 3 = 50·00 „ = 52·9 „ „
No. 3 „ No. 4 = 50·00 „ = 125·0 „ „
No. 4 „ No. 5 = 50·00 „ = 143·5 „ „

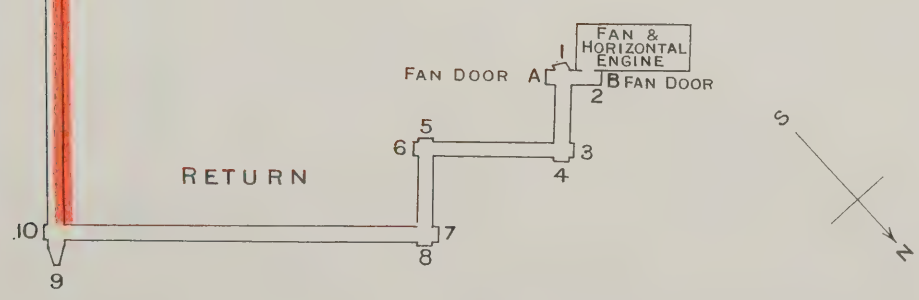
## EXPERIMENT No. 105. SEPTEMBER 30TH, 1909.

| | |
|---|---|
| LENGTH OF INTAKE ... ... ... | 600 ft. |
| SECTIONAL AREA OF INTAKE ... | 41 sq. ft. |
| LENGTH OF RETURN... ... ... | 295 ft. |
| SECTIONAL AREA OF RETURN ... | 28 sq. ft. |
| COAL DUST ZONE, 275 FT., THUS .. | |
| FLAME... ... 730 FT., THUS ... | |




### PLAN.

SCALE: $\frac{1}{960}$ or 80 ft. equals One Inch.




### METEOROLOGICAL CONDITIONS.

| | |
|---|---|
| Barometer ... .. ... ... | 29·3 in. |
| Thermometer, External Wet, 53° F. | Dry, 55° F. |
| ,, Internal ,, 58° F. | ,, 61° F. |
| Humidity, External ... ... ... | 87 % |
| ,, Internal ... ... ... | 82 % |
| Direction of Wind ... ... ... | South-East. |
| Velocity of Wind ... ... ... | Very slight. |
| General State of Weather ... ... (at time of Experiment) | Dull, 11·0 a.m. |

***NOTE.—Relief valves shown by numbers 1, 2, 3, etc.***

## EXPERIMENT No. 105.—September 30th, 1909.

### Main Object of Experiment.

Trial of South African coal, St. George.

### Special Conditions.

Position of igniter, 275 ft. from downcast.

Quantity of air, 64,000 cubic feet per minute.

Velocity of air, 1,560 ft. per minute.

Quantity of dust, 1 lb. per linear foot = 0·4 oz. per cubic foot.

Large cannon, charge 24 oz.; clay stemming, 8 in.

Small cannon, charge 4 oz.; clay stemming, 4 in.

Number of sets of timber in main intake, 30, fixed every 9 ft. from the downcast.

### Name and Particulars of Coal Used.

Seam,

Colliery, St. George.

#### Analysis.

| | Per cent. |
|---|---|
| Moisture | 1·05 |
| Volatile matter | 22·65 of dry coal |
| Fixed carbon | 63·55 „ „ |
| Ash | 13·80 „ „ |

#### Fineness.

| | Per cent. |
|---|---|
| Remaining on 100 mesh | 1·5 |
| Through 100 on 150 „ | 11·0 |
| „ 150 on 200 „ | 2·5 |
| „ 200 on 240 „ | 11·0 |
| „ 240 and finer | 74·0 |

### Result.

Very little pressure was developed. Ignition seemed to hang fire a short time after travelling 100 ft. The flame projected from the downcast end reached 130 ft.

No sets of timber were blown down.

Fig. 95.—Flame from explosion of South African Coal.

## GENERAL REMARKS RESPECTING SOUTH AFRICAN TRIALS.

The Elandslaagte and St. George coal appear to be practically similar except in the quantity of ash they contain.

The results of laboratory treatment, when referred to the ash-free, dry coal (*i.e.*, pure combustible matter present), show that they behave very similarly on distillation, and do not differ widely in their chemical analysis.

The Durban coal, on the other hand, contains more volatile matter and more hydrogen and oxygen than the others, and yields a greater quantity of methane on distillation.

It would appear that the order of their inflammability is

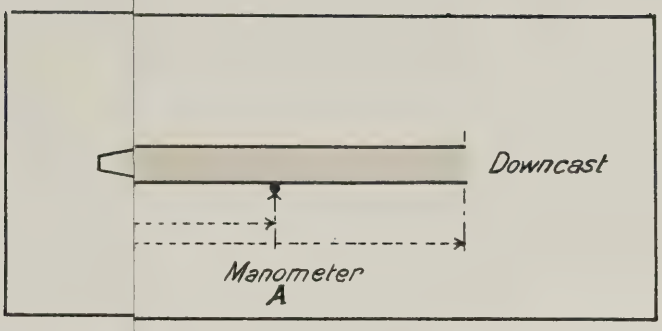
1. Durban,
2. St. George,
3. Elandslaagte,

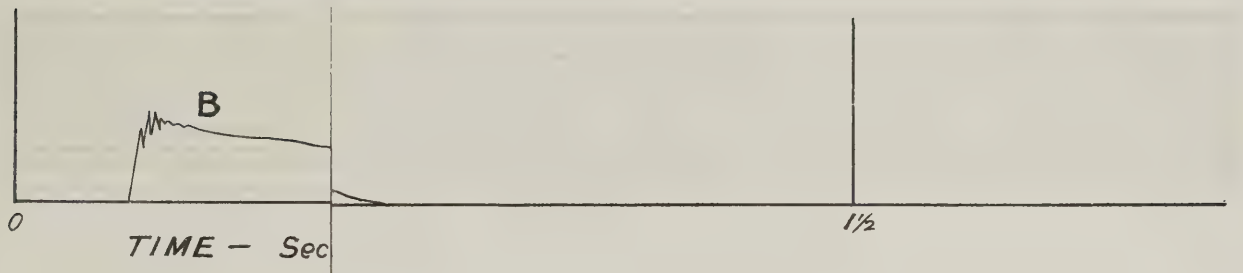
and that that order is determined chiefly by the percentage of incombustible ash present.

The explosions do not seem to develop much force during the first 275 ft. of travel (the total length tried), but it cannot be said at present whether the force would increase in magnitude with increased distance of dust-laden atmosphere, though experiments with Silkstone dust point to this being the case.

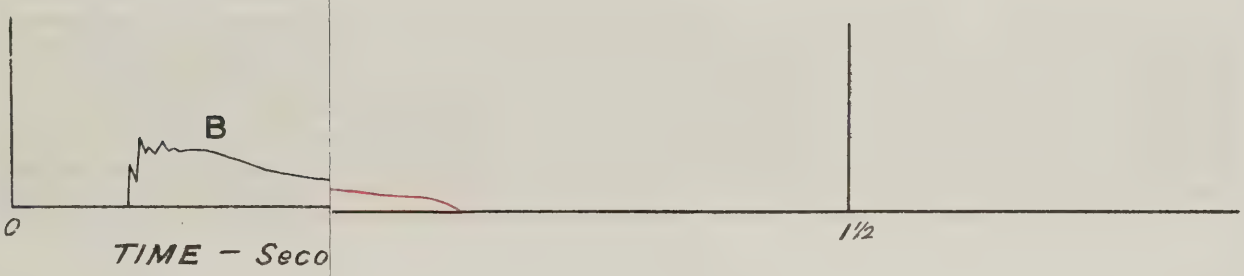
It must be remarked, however, that the pressure of 6 lb. per square inch developed by the 275 ft. of Elandslaagte dust (1½ lb. per linear foot) was sufficient to displace firmly-wedged pit props from the gallery.

# APPENDIX I.

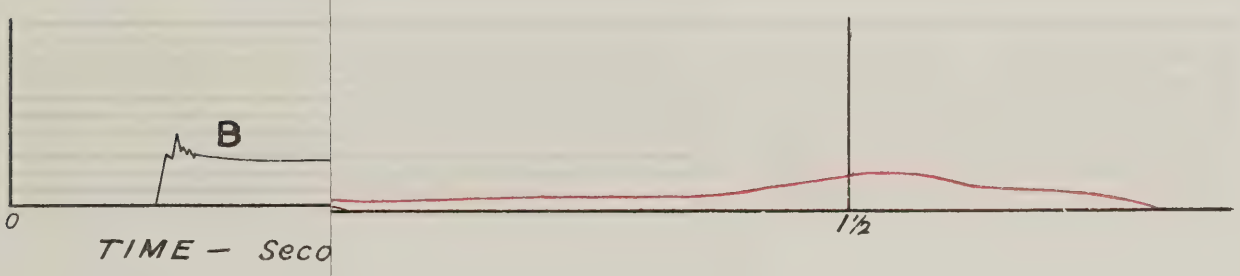


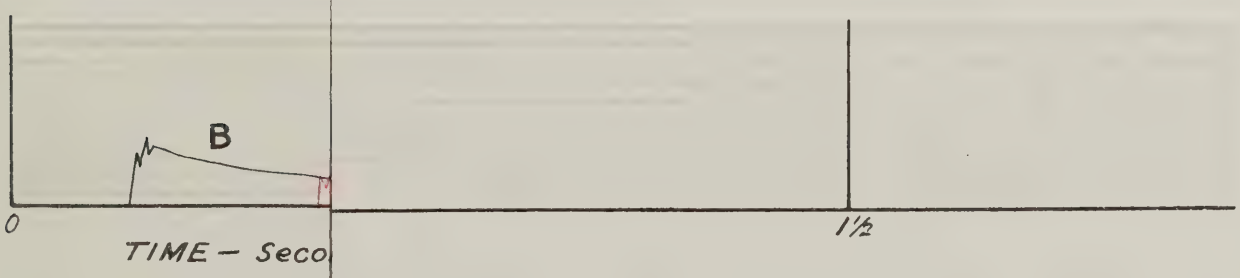

TIME — Sec




TIME — Seco

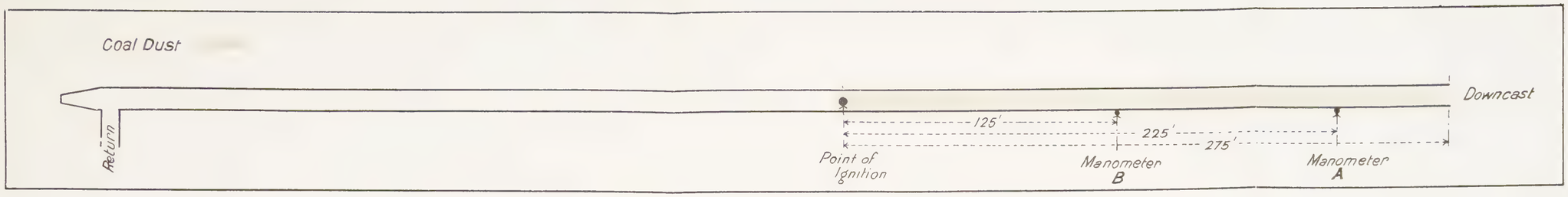



TIME — Seco



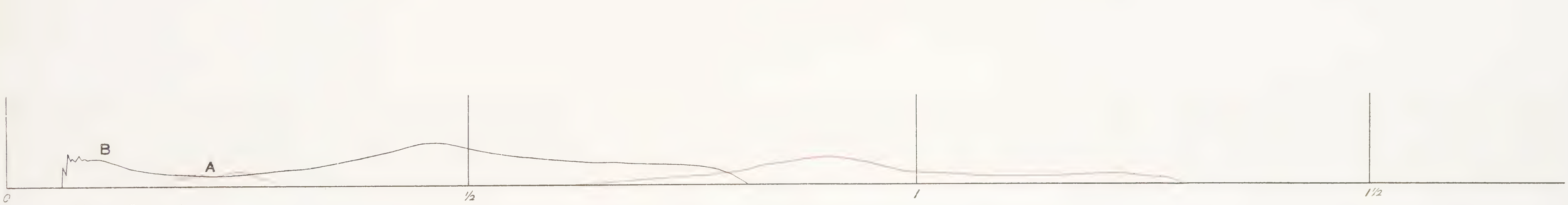

TIME — Seco

...TH AFRICAN COALS.



ELANDSLAAGTE. PRESSURE CURVES. 104 A and B.

PRESSURE — lbs. per sq. in.




DURBAN. PRESSURE CURVES. 102 A and B.

ST GEORGE. PRESSURE CURVES A and B.

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